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J. A. L. Waddell.

THE PRINCIPAL

PROFESSIONAL PAPERS

OF

DR. J. A. L. WADDELL,

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EDITED BY

JOHN LYLE HARRINGTON,

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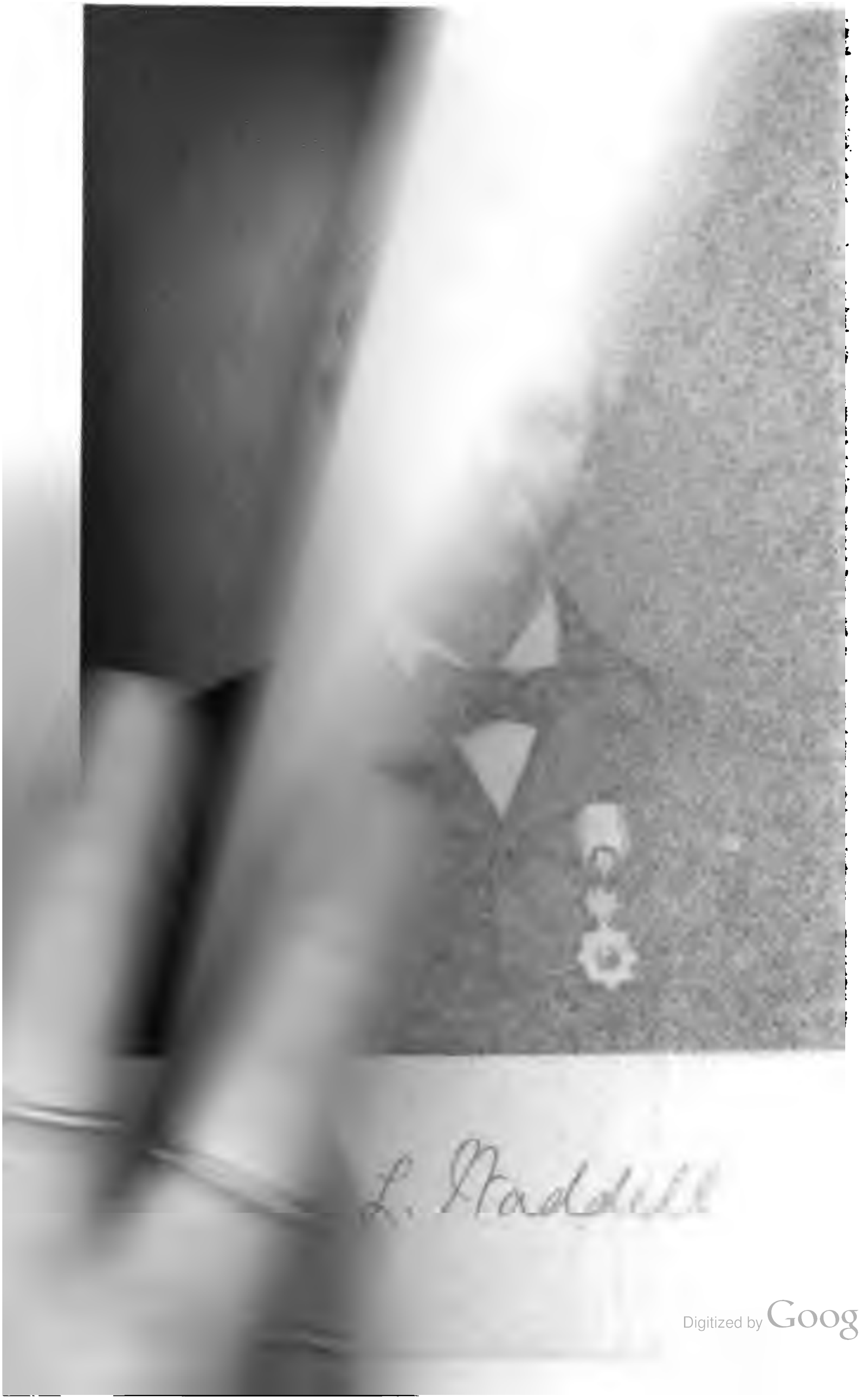

L. Waddell

THE PRINCIPAL

PROFESSIONAL PAPERS

OF

DR. J. A. L. WADDELL,

CIVIL ENGINEER.

EDITED BY

JOHN LYLE HARRINGTON,

CIVIL ENGINEER.

FIRST EDITION.

VIRGIL H. HEWES,
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PREFACE.

IN the course of a friendship which began during my sophomore year in college, when I spent a portion of my summer vacation in his office, and which has grown more intimate with the passage of years, the papers which Dr. Waddell has written have, from time to time, come into my hands. Many of them are addresses which have reached a very limited audience; others have been published by the societies for which they were written and are in possession only of those who were members of the societies at the time of publication; and it has appeared to me that to publish them in book form and make them generally available would be a work of material value to the profession. In my college days I searched the library with small success for such information relating to the work that comes after graduation, as may be found in several of the addresses; and some of the strictly technical papers, with their discussions, have since proved exceedingly helpful to me. Since the publication of technical books is rarely profitable, the preparation of the volume has been purely a labor of love, but I shall feel well paid if the book proves of material assistance in the cause of engineering education, to the young man just entering upon his professional career, and to the engineers in the several lines of which the papers treat.

RAILROAD DRAINAGE and NOTES ON RAILROADING contain much valuable information that is not to be found elsewhere in print; indeed, it is surprising that almost nothing relating to railroad drainage, and very little relating to the practical work of a railway survey, has been published.

THE ADDRESS TO THE KOGAKU KYOKAI (Japanese Engineering Society) is of high historical interest, for it contains a brief but clear view of the condition of the sanitary, manufacturing, and transportation facilities of Japan only twenty years since. It also outlines a future policy for the engineers of that country.

Dr. Waddell's well known interest in civil engineering education is responsible for four papers of unusual value, CIVIL ENGINEERING EDUCATION, SOME NOTES ON CIVIL ENGINEERING EDUCATION, WITH SPECIAL APPLICATION TO JAPAN, A LETTER RELATING TO CIVIL ENGINEERING EDUCATION, and HIGHER EDUCATION FOR CIVIL ENGINEERS. The first was published in Engineering News, and discussed by a number of prominent engineers and educators. The discussions are also very valuable and are reprinted here. Dr. Waddell's six years as a professor, together with his long and successful career as a practitioner, have given him a very broad view of the subject; consequently, his opinions should have unusual weight.

THE ADVISABILITY OF INSTRUCTING ENGINEERING STUDENTS IN THE HISTORY OF THE ENGINEERING PROFESSION raised the question contained in its title and proposed that the Society for the Promotion of Engineering Education undertake the preparation and publication of the history. The valuable discussions upon the paper are also reprinted here.

GENERAL SPECIFICATIONS FOR HIGHWAY BRIDGES OF IRON AND STEEL contains a full exposition of the disreputable methods which still obtain very widely in the designing and contracting for ordinary highway bridges, also some significant data relating to bridge failures.

SOME DISPUTED POINTS IN RAILWAY BRIDGE DESIGNING, and the large amount of valuable discussion upon it, did much to bring bridge design to a uniformly high level, while THE COMPROMISE STANDARD SYSTEM OF LIVE LOADS FOR RAILWAY BRIDGES AND THE EQUIVALENTS FOR SAME continued the treatment of one of the chief points raised in the former paper and supplied the data necessary for the convenient adoption of the simpler method of calculating stresses. The discussion on a paper presented to the American Society of Civil Engineers by E. Herbert Stone, C.E., also deals with one of the disputed points, viz.: the determination of the safe working stresses for railway bridges. The paper entitled ELEVATED RAILROADS and the important discussions upon it form a very complete, modern treatise on the subject. These four papers deal, in a very exceptional manner, with the methods of calculating stresses and with the design and fabrication of railway structures. They have undoubtedly exerted a wide and beneficial influence upon the designing of such structures, and they merit the attention of the thorough engineer as much as anything yet written upon the subject.

THE HALSTED STREET LIFT-BRIDGE describes one of the most unique structures in America, and, while it is improbable that another bridge of that type will ever be built, owing to the later development of the bascule bridge, many of the devices employed are valuable, and the structure will be of especial interest to the student of movable bridges.

FOUNDATIONS FOR IMPORTANT BUILDINGS IN THE CITY OF MEXICO describes a novel method of distributing the weight of a building when the supporting earth has very small bearing value.

SPECIFICATIONS is always an important subject for the engineer engaged in any capacity on any kind of work; consequently, no apology is needed for the insertion of this broad and thorough lecture.

The paper on THE FLOW-LINE BRIDGE REPAIRS reads like a story and would be interesting as such, but it is important as a description of a piece of difficult engineering done in great haste and under dangerous circumstances.

THE RELATIONS OF CIVIL ENGINEERING TO OTHER BRANCHES OF SCIENCE was written very recently and contains a broad view of the field of science, with special reference to the relative position of civil engineering.

Special acknowledgment is due the American Society of Civil Engineers for permission to republish the three papers which appeared originally in the Society's Transactions, and to its Secretary, Mr. Charles Warren Hunt, for kindly assistance in obtaining electrotypes of the cuts for these papers.

To Dr. Waddell I am indebted for permission to publish the papers and for many valuable suggestions.

JOHN LYLE HARRINGTON.

January 16, 1905.

TABLE OF CONTENTS.

BIOGRAPHICAL NOTES.

A knowledge of its author greatly increases our interest and assists in forming an estimate of the value of a book or paper. The logic may be good, the thought clearly and well expressed, but, unless we know that they are supported by experience, we are haunted by a suspicion that the author is only a theorist, after all. We want to know not only what he thinks but why he thinks as he does. These reasons alone make it advisable to insert here a biographical sketch of the author of the papers which follow. No information, however, is of such universal interest and is so eagerly sought as that pertaining to the lives of successful men.

The older man draws courage and comfort from a knowledge that a more successful man had advantages superior to his own and is gratified to find himself more successful than one who has had similar opportunities. He is also strengthened by a glimpse of an honorable conclusion of his own course as evidenced in the lives of others.

But the young man finds in the lives of noted men his own inspiration. He is much encouraged to find that the great man was not always great, but had battles similar to his own to fight. What another has done he believes he can do, and the story of the successful man's life shows him the way. The line of work may or may not be the same; that makes no difference; for courage, intelligence, energy, and integrity will produce the desired results in any line of work. Often a glimpse of a course successfully pursued will solve a knotty problem and make clear to him the procedure most advisable in his own case. Good advice from older men is generally acceptable, but the lessons drawn from experience, one's own or another's, are always more thoroughly learned and, consequently, produce better results.

John Alexander Low Waddell was born at Port Hope, Ontario, Canada, January 15th, 1854. His father, Robert Needham Waddell, was born at Newry, Ireland, in 1815, and came over to Canada in 1831. His mother, who is still living, is a daughter of the late Colonel William Jones of the Seventh Regiment of New York, once Sheriff of New York City, and again a member of the state legislature.

Until his ninth year Dr. Waddell was not sent to school but was taught by his mother at home. Then he was sent to the common or public schools of Port Hope for two years. In 1865 his father was appointed high sheriff of the United Counties of Northumberland and Durham (a high office, which is judicial as well as ministerial under English laws), and removed to Cobourg, the county town. He attended various grammar and private schools there, then spent a year or more at Trinity College School in Port Hope. His sixteenth year found him in rather delicate health and lacking in physical development, the effect of hard study, hence he was sent to China as a passenger on the noted tea-clipper "N. B. Palmer" of New York. The ten months' voyage to Hong Kong and Shanghai and return had the desired effect, for he gained greatly in health and strength during the trip.

Five months were then spent at a business college in Toronto, and in the fall of 1871 he matriculated at the Rensselaer Polytechnic Institute, Troy, N. Y., where he graduated with the class of '75.

His preparation for college followed the good, old classic lines in which the Greek and the Latin languages were prominent. The work in these languages was very distasteful to him and caused him to dislike them exceedingly. He has frequently referred to the time spent upon them as time wasted, and fails to recognize what more than one reviewer has pointed out, their salutary effect upon his English. He is, however, an excellent French scholar, and retains and makes frequent quotations from the Latin. Owing to their lack of training in the Latin and the Greek languages, engineers, as a rule, do not use enviable English. A knowledge of the roots, the foundation of the language, is essential to nicety and facility in its use.

Armed with the degree of Civil Engineer from the oldest and then almost the only school of engineering in this country, Dr. Waddell began his professional career as a draftsman in the Marine Department of Ottawa, Canada, where he spent a few months designing buoys, lanterns, and similar marine appliances.

Then he received an appointment as rodman on the Canadian Pacific Railway, which was being built by the Dominion Government. Fourteen months on preliminary, location, and construction work near Port Savanne brought him much hard work and experience, but small advancement and smaller pay, the usual compensation of the young engineer. He then resigned his position with the Government to make an engagement with several contractors who were building sections of the road, and remained in the bush about four months longer, till the contractors' work was finished.

Following this came about eight months of enforced idleness, probably the most difficult position a young and ambitious engineer ever occupies. Part of this time was spent in coaching his brother, Robert, who entered McGill University very late in the term, but with this assistance was enabled to attain full standing before the end of the scholastic year.

The next summer he obtained a subordinate position on the bridge over the Missouri River, at Glasgow, Missouri, but the great heat and the malaria broke his health and forced him to give up the work after only a month of service.

He soon obtained the position of engineer for a coal mining company in West Virginia, where he did the surveying both above and below ground, and designed and built a ventilating shaft and other mine structures.

In the fall of 1878 the mining work was given up for the position of Assistant to the Professor of Geodesy and Descriptive Geometry at the Rensselaer Polytechnic Institute. This was the beginning of six years' work as an educator, years which afforded time for further study and for writing on technical subjects. Shortly after taking up his work as an instructor, an opportunity appeared to obtain a better position, that of Assistant to the Professor of Rational and Technical Mechanics, and, after several months' study in preparation, he obtained that position, which he occupied until the fall of 1880. While engaged in this work, one of those lasting friendships, which are of incalculable value to both parties, was formed with his immediate superior, Professor William H. Burr, now of Columbia University and a member of the Panama Canal Commission.

In January, 1881, Dr. Waddell was appointed Chief Engineer of Messrs. Raymond and Campbell, a firm of bridge builders whose headquarters were in Council Bluffs, Iowa, and began his work in bridge engineering, the specialty to which he has since devoted himself almost exclusively. This engagement was terminated in the summer of 1882, when he went to Japan to take up again the work of an educator.

Very early he began to write technical papers, many of which were published in the transactions of the "Pi Eta Scientific Society," now the Rensselaer Society of Engineers. Among them were "Railroad Drainage" and "Notes on Railroading," which are reprinted in this volume; "Wave Motion Applied to Light Houses" and "Compensating Trusses," which have not been preserved; and "Bridge Pins, Their Sizes and Bearings," "Highway Bridges" and others which were later incorporated in his book, "The Designing of Ordinary Iron Highway Bridges." These papers attracted considerable attention, and early in 1882, brought from the Japanese Government the offer of the Chair of Civil Engineering in the Imperial University of Tokyo.

July 13th, 1882, he was married to Miss Ada Everett, the only daughter of Horace Everett, Esq., of Council Bluffs, Iowa, and soon after they and his sister, Miss Josephine Waddell, sailed for Japan, where he was to take up his new duties.

The Imperial University was then in its infancy, hence the number of students was small and the work light. The spare time was employed in professional work and in the preparation of his first book, "The Designing of Ordinary Iron Highway Bridges," which was published in 1884 by Wiley & Sons of New York. The science of bridge building was then by no means so well advanced as it is now and very little had been written on the subject, hence the work, which was exceedingly full and thorough, was very widely accepted as a standard text-book and still had a steady sale only six years since, when, at the author's request, it was declared out of print. The theory and much of the practice which it contained are still sound, but iron is no longer the material of which bridges are constructed, hence the book is of no further service to the profession.

Immediately after the publication of this book, the preparation of "A System of Iron Railroad Bridges for Japan" was begun at the request of the University authorities. This Monograph was published early in the summer of 1885, and immediately gave rise to a spirited controversy, for its author had severely criticised the methods of English engineers, as they were exemplified in the Japanese railway bridges, most of which were of English design and fabrication. The "Japan Mail" reviewed the Monograph July 16th, 1885, and immediately, not the Monograph but its author, was bitterly attacked in numerous letters addressed to the "Mail." Throughout the controversy, which continued for nearly a year, the English engineers gave evidence of their professional weakness by avoiding as far as possible a technical discussion of the subject and by confining their arguments to personalities and to generalities, many of which were half-stated or purposely misleading. In his letter of October 7th, 1885, Dr. Waddell states: "Into the merits of the case not one of the writers of the letters in the 'Mail,' attacking my book, has dared to enter. An open, scientific discussion is, apparently, the very last thing my opponents desire. They know that it would make patent to the world the radical deficiencies of the old English system of bridge building." An editorial note adds, "We have published a number of letters—so many that our readers must be weary of the subject—and yet, as Mr. Waddell says, the point at issue is as far as ever from settlement." Thus for three months the discussion had been almost venomously personal on the part of the English engineers. A number of Japanese engineers, an American engineer, Professor W. C. Kernot of the University of Melbourne, and Dr. Waddell carried on the scientific side of the argument, which continued for several more months, but gradually took on a more technical character and resulted in completely establishing the soundness of the memoir. It was a pretty quarrel in which a young man of but ten years' experience won over many old and long-established engineers, but practice has changed so greatly in less than twenty years that its technical interest is small now.

In the spring of 1886, at the end of his fourth scholastic year of Japanese service, Dr. Waddell determined to return to America. He was handsomely treated by the University authorities, and still has in his possession many highly prized presents from Japanese friends. Later the Emperor decorated him by bestowing upon him the order of the "Rising Sun," with the rank of Knight Commander.

Before Dr. Waddell left Japan, Professor Burr, who was then Engineer for the Phœnix Bridge Company, arranged for him to settle in Kansas City, Missouri, as the Western representative of the Phœnix Bridge Company and the Phœnix Iron Company. Though his efforts were, in the main, to be devoted to the interests of these companies, he retained the privilege of practicing as a consulting engineer as well. In order to acquire a knowledge of the companies' methods, the last five months of 1886 were spent in their works at Phœnixville, Pennsylvania, preparing competitive designs and estimates for several important bridges, at least one of which was built.

Realizing that he was quitting permanently the life of a professor, he prepared a very comprehensive paper on "Civil Engineering Education," which was published in Engineering News. It appeared in the issues of January 1st and 8th, 1887, and was discussed in later issues by a number of prominent engineers and educators. It is reprinted, with these discussions, in the pages which follow. It is noteworthy that, while the extremely thorough five years' course advocated has not been adopted, the advance in engineering education has been largely along the general lines laid down in this paper.

January 1st, 1887, Dr. Waddell opened an office in Kansas City, and, from the first, was successful in obtaining contracts for the companies he represented and engagements as a consulting engineer. The street railway companies and several other parties gave him contracts for metal work to be built by the Phœnix Bridge Company, while, as a consulting engineer, he reconstructed the bridge over the Missouri River at Fort Leavenworth, Kansas. The bottom chords of this structure, which is of the Post truss type, had been seriously injured a year or two earlier by a fire which destroyed the wooden floor system; and, though unscientific detailing in the original design made the task difficult, the work of reconstruction was so satisfactorily done that the bridge is still in service.

While representing the Phœnix Bridge Company, he obtained in competition several noteworthy pieces of work, among which may be mentioned the designing of an elevated railroad (valued at about half a million dollars), connecting the Merchants' Bridge and the Union Depot in St. Louis, and the Red Rock cantilever bridge over the Colorado River between California and Arizona. After preparing the preliminary plans, making the estimate, and taking the contract, in a very limited time on the ground, Dr. Waddell was retained by the Railway Company as its Consulting Engineer, to supervise the detailing of the Red Rock bridge at Phœnixville. At the time of its construction this was the longest cantilever span in America, and, until very recently, has only been surpassed by the Memphis Bridge over the Mississippi River. The loads which now pass over the structure greatly exceed those for which it was designed, but it is still doing good service.

As mentioned above, our author sometimes occupied the dual position of representative of the Phœnix Bridge Company, for which he took the contracts, and consulting engineer for the railway company which purchased the structure. As his consulting practice grew, the excellence of design received increasing attention, and it became more and more difficult to bring into agreement the construction which, as consulting engineer, he should obtain for his client, and that which, as contracting engineer, he must offer for the bridge company if he obtain contracts in competition. In consequence, the contracting business decreased in volume until 1892, when he resigned the agency for the Phœnix Bridge Company and the Phœnix Iron Company, and thenceforth devoted himself entirely to consulting work.

On January 1st, 1899, his principal assistant engineer, Mr. Ira G. Hedrick, was admitted to partnership, and the firm became known as Waddell and Hedrick.

A consulting engineer's practice is largely composed of structures of ordinary types and proportions, but Dr. Waddell has been responsible for a very large amount that is noteworthy in both size and character. In 1892 he was appointed Chief Engineer of the Pacific Short Line Bridge Company, for which he designed and supervised the construction of a combined railway and highway bridge over the Missouri River at Sioux City, Iowa. This structure, which cost about a million dollars, consists of two five hundred foot fixed and two four hundred and seventy foot draw spans and the approaches. The foundations are very deep and were sunk partly by the pneumatic process and partly by open dredging.

As Chief Engineer of the Omaha Bridge and Terminal Railway Company, he designed in 1893 a double track railway bridge across the Missouri River at East Omaha, Nebraska. The draw span at the eastern end of the bridge and the pivot pier supporting it were of steel and masonry respectively, while the fixed spans, the other piers, and the approaches were temporary only. The spans were of the combination type, the piers were constructed of piles, and the approaches of timber; but these have recently been replaced under the direction of his firm by a permanent structure with steel spans and masonry piers. The center line of the temporary bridge formed an angle of eleven degrees with that of the permanent structure, hence the new piers and spans were constructed without interfering with the temporary structure or delaying traffic, and when the new portion was completed, the old draw span was revolved eleven degrees and forms a part of the new structure. Owing to the shifting of the channel of the river, it has been necessary to construct another draw span at the western end of the new structure, thus the bridge has two draw spans, each five hundred and twenty feet long, the longest yet constructed. On all the spans provision is made for brackets which will carry a motor track, a roadway, and a sidewalk outside of each truss, but these will not be added till demanded by the traffic.

In 1893 a lift bridge, carrying Halsted Street over the South Branch of the Chicago River, was designed and constructed for the City of Chicago. A paper treating of its construction was presented to the American Society of Civil Engineers and is reprinted here, rendering description unnecessary, but it may be added that the bascule type of bridge has since been so satisfactorily developed that another great lift bridge will probably never be constructed. The structure has been very satisfactory in its operation and will, no doubt, continue in service for many years. Notwithstanding its great height, it is a sightly structure and is a highly creditable piece of engineering.

A steel highway bridge across the Missouri River at Jefferson City, Missouri, is also worthy of mention. It rests on steel cylinder piers which were sunk by the pneumatic process, and consists of a four hundred and forty foot draw span and two three hundred and fifty foot fixed spans and the approaches.

In 1893 Dr. Waddell was retained as Consulting Engineer for the Northwestern Elevated Railroad and the Union Loop Elevated Railroad of Chicago. The former consists of about six miles of four-track structure, built on private right of way, and about one mile of two-track structure built in the street, while the latter consists of nearly three miles of double track structure forming the four sides of a loop around the most congested business portion of the city. The merits of various designs of superstructures and foundations were thoroughly investigated before even the general plans were prepared. The results of these investigations were recorded in a paper presented to the American Society of Civil Engineers in 1896 and form an exceedingly valuable addition to the literature of the subject. The paper, together with the discussions to which it gave rise, appear in this volume.

Dr. Waddell was consulted in the preparations of the plans for the Boston Elevated Railway, and has occupied advisory positions on much other important work.

Since the partnership with Mr. Hedrick was formed, the firm has designed and superintended the construction of a very large amount of bridge work in the United States, Canada, and Mexico, and some lighthouses and bridges for Cuba. The most noteworthy of these structures is a Y shaped railway and trolley bridge over the Fraser River at New Westminster, British Columbia, and the construction of a temporary suspension bridge over the Kansas River at Kansas City. An unprecedented flood swept away one and greatly damaged the second span of the bridge which brought the city's water supply across the river, but with unskilled labor and whatever material was available, Messrs. Waddell and Hedrick repaired the damage and replaced the destroyed span while the flood was at its height. Heroic work under exceedingly dangerous conditions was required, but the city was threatened with disease and was helpless in case of fire, hence it was essential to work continuously night and day for a week until the structure was completed.

Messrs. Waddell and Hedrick have recently been retained to design a railway bridge over the Strait of Canso, Nova Scotia. The preliminary studies indicate that a cantilever bridge having a clear span of more than eighteen hundred feet will be required.

By the time this volume comes from the press, the firm will have nearly completed an elaborate investigation of the properties and economics of nickel steel for railway bridges. This investigation will probably determine whether the large bridges of the future will be of the cantilever or the suspension type.

Although Dr. Waddell has originated many new features of bridge design which are of commercial value, only a few have been patented, the great majority being freely given to the profession. In 1893 he patented an "A" truss bridge which has been extensively and satisfactorily used for railway bridges. It possesses great rigidity and is much more economical than the plate girder for spans of about one hundred feet.

In 1894 he was granted a very broad patent on the principal features of the Halsted Street Lift Bridge, and in 1898 he obtained a patent on an automatic jetty for improving tidal ways. The jetties are provided on the harbor side with a continuous door, hinged at the top, which will open readily and permit the tide to flow into the harbor freely, but which will close automatically and force the outgoing tide to flow through a narrow channel which it will deepen by erosion.

In 1898 a patent was granted to Messrs. Waddell and Hedrick on a suspension bridge stiffened by cables in the form of an inverted catenary placed below the floor instead of the usual stiffening truss. A bridge of this type has lately been constructed in British Columbia.

In 1903 the firm patented a plan for constructing a long-span single-track railway bridge so that it may later be converted into a double track structure. The cost of the single-track bridge will be but slightly greater than that of the usual structure of that type, yet the total cost, when the second track is added, will not be greatly in excess of that of an ordinary double track bridge.

Throughout these years of great professional activity, Dr. Waddell has continued to contribute his quota to engineering literature. Shortly after settling in Kansas City, he wrote a pamphlet entitled "General Specifications for Highway Bridges of Iron and Steel," which was submitted to prominent bridge constructors throughout the country. A second edition, containing discussions by various engineers and contractors, was distributed about a year later. In 1893 a paper on "Some Disputed Points in Railway Bridge Designing" was written and presented to The American Society of Civil Engineers. This was followed by a paper on the Halsted Street Lift Bridge and a very full and thorough paper on Elevated Railroads, both of which were presented to the same Society.

"De Pontibus," a very valuable book treating of the general principles of designing and detailing bridges and supplementing the usual text books on that subject, was published by Wiley and Sons in 1898. Two years later the same firm brought out a volume entitled "Specifications for Steel Bridges." Both have been very favorably received by the engineering profession.

A short paper on "Foundations for Important Buildings in the City of Mexico" and another on the "Flow Line Bridge at Kansas City" complete the list of technical papers.

Dr. Waddell's interest in engineering education has never flagged, and much of his time has been given to matters pertaining to it.

Early in 1882 McGill University conferred upon him the *ad eundem gradum* degree of Bachelor of Applied Science, and in June of the same year gave him the degree of Master of Engineering, after he had passed a very severe examination. The same institution recognized the high value of his scientific work by conferring upon him the degree of Doctor of Science in April, 1904; and in June of the same year Missouri State University honored him with the degree of Doctor of Laws.

In addition to the paper on Civil Engineering Education, previously mentioned, papers on Civil Engineering Education in Japan and on the Advisability of Instructing Engineering Students in the History of the Engineering Profession have been presented to the Society for the Promotion of Engineering Education. Numerous lectures have been prepared and delivered to the students of various educational institutions throughout America. Several of the most valuable of these are preserved in this volume.

A report recently made to the head of a prominent educational institution and an address on "Higher Education for Civil Engineers" contain Dr. Waddell's latest ideas on the subject of instruction in engineering.

At the invitation of the Directors he addressed The International Congress of Arts and Science at The Louisiana Purchase Exposition in September, 1904, upon The Relations of Civil Engineering to Other Branches of Science. The address is printed in the succeeding pages. His interest in the engineering societies has always been strong. He joined the Pi Eta Scientific Society, now the Rensselaer Society of Engineers, in 1872, and was elected a Member of the American Society of Civil Engineers in 1881; an Associate Member in 1883 and a Member of the Institution of Civil Engineers in 1899; a Member of La Société des Ingénieurs Civils in 1887; the Canadian Society of Civil Engineers in 1903; and an Honorary Member of the Kogaku Kyokai, the Japanese Engineering Society, in 1886. In 1893 he became a Charter Member of the Society for the Promotion of Engineering Education. He was a Charter Member of The American Society for Testing Materials and chairman of its committee on structural steel. He was a Member of the Engineers' Club of Kansas City, which is now defunct, and resigned his membership in the American Society of Mechanical Engineers, the Western Society of Engineers and the Engineers' Club of Philadelphia.

In June, 1904, the Missouri State University chapters of Phi Beta Kappa and Tau Beta Pi elected him to honorary membership.

Every successful engineer works hard; there is no royal road to success in any branch of the profession; but Dr. Waddell has found time from an exceedingly active professional life to enjoy much true sport. Whist has occupied much of his attention and he was thrice President of the Kansas City Whist Club, and each year several weeks are devoted to shooting and fishing. He is acquainted with every part of this continent where good sport is to be had. He has caught the tarpon in the Gulf of Mexico; the bass, pickerel, and muskellunge in Wisconsin and Minnesota, and the salmon in Canada; has shot deer in Arkansas, deer and elk in the Rocky Mountains, and small game in many sections of the country. A recent number of "Forest and Stream" contains a reference to him as a sportsman which is well worth reproducing here.

ENGINEERING AND FISHING.

Our frequent contributor, Mr. J. A. L. Waddell, of Kansas City, Mo., is known to the readers of our angling columns as a successful tarpon fisherman and angler for other big game fish. Mr. Waddell is one of the most distinguished bridge engineers of the United States, and has undertaken enterprises also in Mexico, Cuba, Canada and Japan; for his work in Japan he has been decorated by the Mikado. Engaged in important work in bridge building in various parts of the country, he enjoys the rare good fortune of finding opportunities of indulging in his favorite recreation in connection with his professional duties. His engineering enterprises in Mexico have borne fruit for tarpon fishermen in the series of articles on tarpon fishing written out of his experiences there. On the way to and from British Columbia, Mr. Waddell has found opportunity to test the rainbow trout; and while on professional visits to Nova Scotia he has drawn attention to the possibilities of the sport of tuna fishing in Atlantic waters. Mr. Waddell is the author of several authoritative works on bridge engineering, and, as might be expected, his fishing papers are intensely practical. They have less of the poetry of angling and more of the useful, instructive and definite description of tackle and modes of fishing.

It need not be added that Mr. Waddell is a strong advocate of the value of field sports from a purely business and professional point of view. He believes in play as a necessary complement of work; and not only does he practice the doctrine, but on occasion he preaches it and urges it upon the younger men in the profession. We have before us an address delivered by Mr. Waddell to the graduating class at this year's commencement of the Rose Polytechnic School. The burden of the address is to celebrate industry, application, study, and work as the essentials of professional advancement and success; but with all these the value of recreation from toil is not forgotten. One of the concluding paragraphs may well be quoted as having application to other professions than that of the engineer:

> "By this time you all have probably come to the conclusion that you have been listening for the last half hour or more to an old fogy, who thinks that there is nothing in life worthy of consideration but work, work, work, and who can talk on nothing but technical subjects. If this be so, I by no means blame you, for you would seem to have reason on your side; nevertheless, you would be entirely in the wrong, because I am a firm believer in legitimate relaxation of every kind, and in a man's getting all the pleasure he can out of life. Perhaps, too, I could talk of things that are far from technical, such as hunting the great game of the Rocky Mountains, canoeing on lake and stream, the shooting of rapids, travels in foreign countries, gunning for wildfowl in the marshes, sports afield with dogs and gun, fly-fishing for trout in the streams of the far North, and struggling with the gallant tarpon on the waters of the Gulf of Mexico; but it was not to discuss such subjects as these that your president brought me here, so I shall desist, only remarking that the more you mix these things and other sports and amusements in with your work, the better will it be for you both physically and mentally, the longer will you live, the more will you accomplish, the more satisfactory will be the results of your work, the better men and citizens will you become, and the more interesting and agreeable will you prove to all with whom you are thrown in contact."

It is hardly necessary to add that throughout his active career Dr. Waddell has always found time to devote to his many close and true friends. Many a young engineer owes much of his inspiration and success to the friendship and personal assistance of this busy engineer, while many more have been encouraged and strengthened by the many lectures and addresses which he has snatched the time to prepare and deliver to them. He is a devoted husband and father, a public-spirited citizen, and a thorough sportsman, while his energy and his ability have gained for him a high position as an engineer.

NOTES

ON

RAILROAD DRAINAGE.

INTRODUCTORY NOTES.

NOTES ON RAILROAD DRAINAGE was written in 1878, shortly after its author had completed a term of service on the construction of that portion of the Canadian Pacific Railway which lies northwest of Lake Superior. The line runs through muskegs or swamps, separated by short stretches of earth or rock, and, as the rainfall in that section is great, the drainage was a very important problem, and received very close attention. The paper was presented to the Pi Eta Scientific Society of the Rensselaer Polytechnic Institute, by which it was soon afterward published, but the pamphlet is no longer available. In a thorough search through technical literature, the editor has been unable to find anything more than a casual and minor treatment of the subject of railroad drainage, hence, though the paper was written more than twenty years since, its matter is as fresh and timely as though it were written yesterday.

At first thought it would appear that the railroads of America are already built, but a glance at the statistics of the subject will show that the amount of new line under construction at any time is enormous, hence it is a matter of regret that the subject is not fully treated in the principal books on railroading. Both the student and the practicing engineer who has not had great experience in this particular line of work should find the paper of unusual value. It was written while the difficulties encountered and overcome were fresh in the author's mind, hence the treatment of a difficult phase of the subject of railroad drainage is very full and thorough.

NOTES ON RAILROAD DRAINAGE.

The usual answer to the question, "What are the requisites for a railroad?" is, " Light grades, easy curves, and an equality of cuts and fills." There is one, however, which is still more important than any of these, but which is too often overlooked—a good system of drainage. In a mountainous country heavy grades and sharp curves are unavoidable, and in cold climates cuts, especially light ones, are objectionable, because they are liable to fill with snow. A continuous three-foot bank makes the best kind of a road. If the drainage of any railway be imperfect when the grading is finished, there will be trouble until the imperfections are removed, to accomplish which will cost far more than to complete the work properly at first.

When the grading is begun in dry weather, the drainage provided is often inadequate, owing to ignorance in regard to the volume of water passing the right of way. The tap drains are made too small, and under drains, both longitudinal and transverse, are left out in many places where considerable water passes in the wet season. Often, too, the embankment is built so close to the sides of a river or creek that, when high water overflows the banks, a great deal of material is washed away. To destroy an embankment it is not necessary for the water to back up greatly; if it stand but a few inches above the berm, the base will be gradually undermined, and a settlement will take place. In improperly drained clay cuts, the road bed often becomes so soft that the ties and rails disappear beneath the mud.

Diversions which run alongside the slopes are sometimes made so small in cross-section that the water in rising cuts away the side of the embankment for many hundred feet. When this occurs a breakwater will have to be built as a protection until the water subsides sufficiently to permit the diversion to be deepened or widened, as may be required.

In building a road through a swampy country, or one that is at all wet, the first thing to be done after the clearing is finished is to dig good tap or off-take drains. This, in addition to being a great advantage to the road, is a still greater advantage to the contractor, because swamps that are well drained can be worked several cents per cubic yard cheaper than those that are not, and the work can be done more quickly, as four gangs can be started at once after a drain has been carried across the roadway.

There are many slightly different methods of laying out off-take drains. The one usually employed by the writer is as follows: At the lowest point of the swamp the depth of the side ditch is made three feet and that of the off-take three and a half feet; in the first hundred feet a fall of half a foot is given to the bottom of the drain, so as to insure a good initial velocity for the water; afterwards a fall of one-tenth of a foot in a hundred feet is sufficient. The drain should be continued until it runs out to grade. Sometimes there is difficulty, where the underbrush is thick, in finding the lowest ground. After running a few hundred feet without finding a satisfactory fall, it is a good plan to turn off a line, as nearly as may be, parallel to the centre line of the road, find which way the ground falls and the lowest point on this off-set line, then go back to the place of starting, turn off so as to strike this point, and proceed as at first. The lowest ground can often be found by following running water, and by looking to the quality of the timber, the underbrush, the color of foliage, and the character of vegetation. It is ordinarily supposed that swamps are situated on the lowest ground, but sometimes they are found in elevated positions. Often, too, lakes and creeks occupy the summits of swamps or muskegs.

After an off-take drain is run out to grade, it is well to go over it and straighten out the centre line, so as to avoid angles and sharp curves, even if the quantity of material excavated be slightly increased in consequence.

The side ditches should always be laid out so that they fall toward the off-take, even where the embankment has a level grade. If, during the progress of the work, a ridge of boulders be encountered in the side ditch, calculations should be made to determine whether it would be cheaper to cut through it or to put in an off-take on each side of the ridge. The latter method is to be preferred if its cost does not greatly exceed that of the former, for the greater the number of off-takes the more complete will be the system of drainage. If the ridge of boulders tails off within a reasonable distance from the centre line, the side ditch may be carried around its base.

In large, level swamps where there is considerable water, drains should be put in every fifteen hundred or two thousand feet. The shape and size of drains and ditches depend on the quality of the material to be excavated and the quantity and velocity of the passing water.

When the embankment is formed wholly of material excavated from the side ditches, the cross-section of the latter is generally greater than that required for drainage. Care should then be taken to prevent the workmen from obtaining the extra material by increasing the depth instead of the width of the ditches, which, owing to their objection to long hauls, they are liable to do if not closely watched.

In muskegs or peaty swamps the material stands better when the sides of the ditches are vertical than when they are sloped, owing, probably, to the great number of roots it contains. Hard clay stands well with a slope of one to one, and sand or gravel with one and a quarter or one and a half to one, while quicksand will fill in from almost any slope.

The width of the bottom of an off-take should never be less than three and seldom more than ten feet. It is sometimes made as small as one and a half feet, but this is false economy, for a single boulder falling from the side is sufficient to prevent the water's passage. Drains should be made large enough in the first place; for the double casting of a portion of the material and the necessity of having the navvies work in water increase by at least one-half the cost per cubic yard for enlarging them. It is surprising how much more a workman can do if he have a good, clear run for the water behind him; sometimes he can take out twice the quantity of material that he could have taken had the water backed up on his work. Contractors who let swamp grading by the yard in small sections of two or three hundred feet make a great mistake; for the water, having no chance to escape, fills up the pits so rapidly that dams have to be left every few feet. These, of course, must be removed before the work is completed.

After the centre line for a drain has been laid out, the ground should be cleared from fifteen to thirty feet or more on each side of it, according to the width required for drain, berm, and casting room. The brush should be burned or carried off the clearing, for in cold countries trouble is experienced in cutting through the frost, which, in densely wooded swamps, is often perennial. Brush should never be left over winter on the right of way, because by preventing the snow from reaching the ground, it allows the frost to penetrate freely. The width of berm depends upon the quality of the material and the quantity to be excavated. In small drains where casting is allowable, four feet should be the inferior limit; but if the material be soft, a ten-foot berm will be required.

The obstacles usually encountered in drainage are the filling in by deposit, the caving in of the sides, and the rising of the bottom of the ditch. The first may be overcome by clearing away from the mouth of the drain, for a distance of fifty or a hundred feet, all the stumps, large roots, and other obstructions, which are in the line of the running water; the second may be obviated by changing the slope ratio of the sides; but there is great difficulty experienced in overcoming the third. If lumber can be procured, the best method is to build a good box-drain of one and a half inch plank, and fasten it firmly to posts driven beside it. The ends of the box should pass the place where the difficulty has been encountered, otherwise it will be quickly filled. If lumber cannot be obtained, some substitute must be found. After seeing several methods tried unsuccessfully, the writer has proposed the following for beds of quicksand or liquid clay across which tap drains often have to pass. Drive with a maul posts about six inches in diameter and five or six feet long, spaced fifteen inches apart along the bottoms of the slopes; cut bundles of brush, poles three inches in diameter and four feet longer than the width of the base, and six lines of heavy poles, and lay them all along the sides of the drain: commence a few feet from the end of the quicksand, excavate to the depth of a foot below grade between the posts, and fill the excavation with the brush; then place the three-inch poles across it and allow their ends to pass between the posts. After finishing about thirty feet of the drain, lay the heavy poles, three deep, longitudinally outside the posts and across the ends of the light poles, retaining them in position by stakes. Outside of these, place brush backed up with earth. Brace every fifth or sixth pair of posts internally so as to prevent their being forced toward each other by the pressure of the slopes, and after carrying the work past the end of the quicksand, cast out any material that may have been deposited on the brush.

It is often practicable and advisable to run two or three off-takes into one: care should then be taken to make the cross-section of the main portion large enough to empty the branches.

An interesting system of drainage is that of Mud River, between Linkoping and Port Savanne Stations, on the Canadian Pacific Railway. The location of that part of the line was made by Mr. W. McLeod Maingy, C.E., during the summer of 1876. He encountered this stream quite unexpectedly, for the ground had been rising gradually for three-quarters of a mile through an open muskeg that had no solid bottom at a depth of ten feet. The stream at the crossing was about thirty-five or forty feet wide and ten or twelve feet deep, and the banks for some distance on each side were afloat. While searching to the south for a place to cross, Mr. Maingy discovered that he had succeeded without knowing it, for the stream had split up into small branches which found their way to the Savanne River, some miles distant, by means of underground passages, or by percolating the swamp. He immediately informed the Department of the necessity for drainage to the south before the grading could be proceeded with, but, notwithstanding his advice, the embankment was commenced during the next winter under the direction of a section engineer by borrowing from side pits three feet in depth. Then came the difficulty; the banks sank, and the pits filled from the bottom, owing to the upward pressure of the water below. It was imperative that something be done before the work could proceed, and, knowing that the ground fell in the direction of the centre line, the section engineer commenced to run two side ditches to the eastward to reach the lowest point of the swamp shown by the profile (a distance of three-quarters of a mile from the river) and to make there an off-take drain to the southward. The south side ditch was made twelve feet wide, the north one much smaller. The material excavated was of a peaty nature and very light; but whatever could be used was put into the embankment. Still there was a great deal of waste, for a large portion of the bank was already made from the borrow-pits. The off-take drain, or, more properly speaking, the canal, was completed before the side ditches were half finished and had slopes of about one and a half to one, instead of having the sides vertical, as they should have been. The section engineer having left the road, Mr. Maingy, who had the next section, was then placed in charge of the work. He completed the side ditches, and found, as he had expected, that the water was lowered but little more than a foot. In places the ditches filled from the bottom as fast as the graders could excavate them. He overcame this difficulty by cutting poles four feet longer than the width of the base, sharpening them at both ends, and driving them horizontally four feet into one side of the ditch, then back two feet into the other. These poles were placed about two feet apart. When the ditches were completed the canal was found to be insufficient to carry off the water from the river and the surrounding country. The work was no nearer completion than at first, for it was found impossible to keep the embankment up to grade. The swamp had to be drained before the advent of winter, which would stop operations, therefore the division engineer consented to try the method originally proposed by Mr. Maingy, viz., to run a large diagonal drain from the river to the neighborhood of the end of the canal. This drain was made ten feet deep and nine feet wide, with vertical sides. The total fall obtained was fourteen feet. The drain was finished in December and lowered the water four and a half feet, drying up the side ditches and rendering them useless except in cases of extremely high water. Had this method been followed at first, and had narrow side ditches been dug so as to drain the swamp completely before the grade had been established, the work could have been done for not more than half what it finally cost.

To drain a lake, ascertain the maximum quantity of water flowing out of it, the fall obtainable, and the best form of cross-section for the off-take; then calculate the maximum depth of water at the head of the drain, the bottom of which should be that depth below the required level of the lake.

Diversions should be made whenever a stream crosses the right of way at an angle less than thirty-five degrees, where there are several crossings of the stream at short intervals, and whenever the channel is too small for the quantity of water it carries in the wet season. They are often made to avoid the construction of a culvert or a bridge or to lower the surface of a stream which is higher than that of formation level at the crossing.

The cross-section of a diversion should be calculated for the maximum quantity of water and a velocity ascertained from the fall shown by the levels and from observation. Very often the diversion should extend above as well as below the centre line of the road and should cross it as nearly as practicable at right angles. It should be made as straight as possible and, if curves are unavoidable, they should be placed as far as practicable from the centre line of the road, so as to avoid any damming of the water in them. If the fall be slight, the stream should be cleared of logs and roots for some distance below the end of the diversion. Occasionally a diversion may be avoided altogether by clearing out the stream, as the removal of boulders will often lower the water level sufficiently, especially if the current be rapid. The beginning and end of a diversion should follow the direction of the running water at those points, otherwise a dam will have to be built at the beginning to deflect the water into the new channel, while at the end a few inches of head will be lost owing to curvature. At the end of a diversion the grade of the bottom should be at about the same level as that of the stream, but at the beginning it should be several inches lower. In short diversions it is no matter if the bottom be level.

The drainage of cuts is a very important feature in railroad construction. Catch-water drains or little gullets are dug on the upper side of the hill at a distance varying from five to twenty-five feet from the slope stakes, to draw off the water which would otherwise flow down the slope into the cutting. Through cuts should have a catch-water drain on each side.

The ordinary depth of a catch-water drain is one foot, and the width on the bottom is about the same. The material should be cast on the side next to the cutting. It is allowable to change the course of the drain so as to avoid a large stump or rock.

Large dips in cuttings cause a great deal of trouble, necessitating a deepening of the catch-water drains, or what is still worse, the leading of the water down the slopes. When this is unavoidable, a box drain must be used for the purpose. Occasionally an off-take can be employed in a cutting, to empty either a catch drain or a water table.

A level grade through a long cut should never be employed. It is far preferable to rise to the centre and descend again in order to prevent water from standing in the cut. If the material in the cutting be dry, water-tables or shallow drains at the bottoms of the slopes will be sufficient; but if it be wet, under-drains will be needed. These are made about two and a half feet wide and three or four feet deep, without any slope. A layer of poles is placed on the bottom, then a few layers of stones, then gravel to within a foot of the top, and, finally, a layer of fine brush and some more gravel. The brush is used to keep the material of the slopes from filling up the drains. A stout box open at the bottom and underlaid with brush or straw, is a good substitute for the poles and stone. The bottoms of drains in level cuttings should fall both ways from the middle.

In quicksand cuts it is well to make three longitudinal drains, with a box in the bottom of each; and in no case whatsoever should a level grade be run through a quicksand cut that is more than four hundred feet in length.

In both cut and fill the road-bed should be rounded off so as to be half a foot lower at the sides than at the centre, in order that it may shed the water readily; and in the embankment this form should be kept from the very start. Roots, moss and frozen material ought never to be put into an embankment; for, although the first cost is greater, it is cheaper in the end to waste them, as a bank containing them will never settle properly, but will continually wash away. It is owing to this error that the quantities on Sec. 4, Contract 25, C. P. Ry., are double those called for by the profile.

Where an embankment does not exceed six feet in depth, stone or pole drains well covered with brush may be used to carry a very small stream across the right of way. For a stream less than eight square feet in cross-section, a wooden box drain is most economical, but it should not be used in a bank exceeding five feet in depth, owing to the difficulty of replacing it. For high banks trestle culverts should be employed. Stone or concrete arches are, of course, preferable to either of these, but they are comparatively expensive, and in many countries there is no stone of which to build them. Where the ground is soft, pile bridges or trestle culverts on piles are used. The excavation for a water-way across a road ought to be placed opposite the off-take drain, and should be at right angles to the centre line of the road.

By a careful study of the drainage and the adoption of such expedients as the deepening of a borrow-pit to admit the passage of a drain or the avoidance of a bridge by running a stream through a low cut, much expense can be saved. Cases such as those mentioned occur occasionally in every railroad engineer's practice, and upon his skill and ingenuity in their treatment the cost of the construction and maintenance of the road will greatly depend.

COMMENT.

The location of a new railroad is commonly governed by the business advantages of reaching certain points and the economies of operation, the advantages of thorough construction taking third place in the consideration of the promoters. Funds for a new line are generally difficult to obtain, hence every effort is made to construct the road cheaply; its early completion contains the promise of early dividends, therefore speedy construction is also of great importance; but both low first cost and rapid construction are opposed to thorough work; consequently, the maintenance of a new road commonly involves much reconstruction and is very expensive. Often bridges, trestles, and even culverts are constructed of timber, ballasting is deferred, and temporary locations are adopted in order to hasten construction and reduce the first cost. Under these conditions it is not surprising that adequate provision is rarely made for carrying off the surface water and for draining the road bed.

Owing to these demands upon the locating and constructing engineers for haste and cheapness, the Western and Southern roads in this country and the roads in nearly all new countries have suffered greatly on account of improper drainage. The cost of repairing or rebuilding culverts and bridges, draining soft spots, and replacing washed out embankments is great, but it is a bagatelle compared to that of a wreck, or even the delays and consequent loss of business. The haste with which it is necessary to make repairs after a flood again requires temporary construction, and the evil of the original defect is continued until an exasperated management is compelled to make permanent and adequate repairs.

Too small culverts are exceedingly common; in fact, they are not unknown on the older and better maintained roads. It is often difficult for the constructing engineer to determine from the meagre data at hand how large culverts and drains should be. His work of construction must proceed in haste, and questions of rainfall and the area drained to an opening must often be left to the more deliberate consideration of the engineer of maintenance of way. This more expensive procedure could often be avoided by employing a larger engineering force on construction.

One of the most frequent causes of trouble along our Western rivers is inadequate riprapping where it is necessary to construct the roadway close to the bank. This generally occurs at a sharp curve where the stream is cutting into the bluff and where, consequently, anything but first-class protection will be cut away. In several instances which have come under the editor's observation, traffic has been diverted to circuitous routes or stopped altogether for considerable periods by failure of the protection at some one point on the line. Then there is the excessive expense of making repairs while the flood is at its height, though thorough work could have been done at very low cost originally or during the dry season.

Where the line crosses the valley of a creek which is subject to sudden rise, the embankment is often made just high enough to keep the rails above the known high water mark, while the water way is narrowed to save bridging and subsequent floods are greatly obstructed. Then the backed up waters cut the embankment or soften it so that the rails sink in the mud. In either case traffic is delayed, even if wrecks be averted, and expenses far greater than those of a higher embankment and a longer bridge are incurred.

The use of wooden box drains, stone or pole drains covered with brush, and similar expedients for carrying a small stream across the right-of-way, is exceedingly expensive ultimately, for sooner or later the wood decays or the stone becomes clogged and a soft spot in the embankment results. If stone be available a permanent drain may be cheaply and quickly constructed; otherwise, the vitrified clay pipe which is made in a variety of suitable sizes and in lengths which make its transportation easy should be used. Both the first cost and the expense of laying it are small. Very ordinary foresight will enable permanent drains of proper dimensions to be constructed with it almost as cheaply as the very temporary expedient which is usually expensive to replace.

Tile drains laid about three feet below the bottom of the side ditches will be of great assistance in obtaining a satisfactory road bed and their cost is comparatively small. They should be surrounded by a layer of gravel or broken stone. In alluvial countries where these are not easily obtained a coarse brick may be cheaply made by burning the alluvium, using for fuel the brush and timber cleared from the right of way.

A fair quality of ballast may be cheaply prepared in the same way.

The use of pile trestles in soft spots is a very satisfactory expedient, for the embankment may be made by filling at convenience during the life of the trestle. This ensures a good embankment at slight additional expense, for the cost of the trestle will be almost balanced by the cheaper filling, and will save much time, when time is of most value, during the construction of the road.

The huge expenditures for betterments incurred in recent years by many of the more important railroads are certainly in no inconsiderable measure due to the unnecessary adoption of expedients during construction. The engineer of construction is frequently forced by the demand for low first cost to adopt constructions of which he does not wholly approve. Too often this is due to the fact that it is easier and pleasanter to accept the dictum of the financial managers of the road than it is to make a forcible presentation of the true economy of the case, which generally involves high first cost and begets a reputation for extravagance.

Faulty estimates of cost are not infrequently the cause of bad construction. It is a part of good engineering to obtain satisfactory results for the least possible sum of money, but it is not the part of wisdom to count all factors on the favorable side when making up estimates of cost. Too low estimates result in inadequate appropriations and consequent cheapening of the work. This error is so frequent that financiers are very apt to accept the engineers' estimates with misgiving or to add to them in their own consideration of the financial problem.

NOTES

ON

RAILROADING.

INTRODUCTORY NOTES.

NOTES ON RAILROADING was written early in 1879, while Dr. Waddell was an assistant professor at the Rensselaer Polytechnic Institute, and was read to the Pi Eta Scientific Society, now the Rensselaer Society of Engineers. It was then published in the transactions of this Society, from which it was copied by Van Nostrand's Magazine. A brief discussion of it by Mr. H. P. Bell, then an engineer on the Canadian Pacific Railway, also appeared in a later number of Van Nostrand's Magazine and is reprinted here.

When the paper was written the literature of the subject was exceedingly meagre. Even at the present day the text-books present only the theoretical phases of the subject and fragmentary articles in the technical periodicals are the only generally available source of information in relation to its practical side. The chief engineers of many of the larger railroads issue brief instructions to the engineers under their direction, but generally the young engineer must gain his knowledge by the personal instruction of his superiors or by hard knocks in the good, old way.

Under these circumstances, no apology is needed for reproducing this paper, which embodies the results of nearly two years' experience in varied construction on the Canadian Pacific Railway. Railroad engineering was a well developed science when the paper was written, hence the subject matter is very closely in accord with the best present practice.

This country is so well served with railways that we are accustomed to think the great work in that line all done, but an examination of the statistics of the subject shows that the amount of new work under way is always very large, while the work of straightening and improving old lines calls for enormous expenditures annually. As the traffic increases the established companies are warranted in expending large sums in shortening their lines, reducing curves and grades, and constructing more permanent roadway.

More engineers are entering railway work than ever before, hence the need of a thorough treatise on the practical phases of the subject was never greater. The problems of location are very thoroughly treated in a number of works on that subject, and Wellington's monumental work contains a great mass of valuable though ill-arranged information; but the practical phases of construction are nowhere, to the editor's knowledge, comprehensively treated in all the detail that is desirable, for the numerous small points which are commonly considered unworthy of full discussion constitute the difference between fair and thoroughly satisfactory construction.

NOTES ON RAILROADING.

The subject with which I beg leave to occupy your attention this evening and, if such be your pleasure, at some future meetings also, is Railroading. It is not my purpose to cover in these notes the whole subject of Railroad Engineering, but merely to convey to you, who are soon to become engineers, an idea of what *practical* railroading really is, in order that you may not feel at a loss how to proceed should you, at any time, be called upon to take charge of a survey or construction party. The facts here stated have been obtained principally from personal observation and experience, and I have avoided as much as possible dealing with those parts of the subject which are treated in standard works; nevertheless I have had to touch upon some of them lightly in order to make what I have written clear and continuous. In dealing with such a technical subject as this, it is impossible to avoid repetition of certain words and expressions, so you will please make all due allowance for the phraseology of what I am about to read to you, and do not expect to hear the flowing language and easy style which one would employ in dealing with a literary subject. Especial reference is made to "bush work," for by far the larger portion of American railroading partakes of that character; besides, nearly all the difficulties met with in running a line through a well-settled country or prairie land are encountered in the bush, in addition to many others of an entirely different nature. The building of a line of road may be divided into four distinct steps, which will be treated separately: they are Exploration, Preliminary, Location, and Construction.

EXPLORATION.

The data usually given to the engineer who makes the exploratory survey are the termini of the line, the various points through which it is to pass, and the general character of the road. The last is determined by the principal object for which the road is to be built, whether for passenger or freight traffic. If for the latter, whether it is to be heavy or light influences the grades, and, therefore, the length and cost of the road. The heavier the traffic, the more expensive will usually be the first cost of construction, for hills must be avoided or cut through that would otherwise have been run over, thus augmenting the expense by increasing the length of line or the quantity of material to be moved. On most roads the heavy freight goes in one direction, hence in that direction the up grades should, if possible, be the lighter. Another reason for having two maximum grades is that, in case a summit is to be reached, the engineer, by having a light maximum down grade in the direction of the heavy traffic, will be prevented from making the profile too irregular. Having given, then, the termini, the intermediate points, and perhaps the maximum grades also, an exploratory survey is made by an experienced engineer traversing the country, so as to report whether, in his opinion, a practicable route can be found, and, if so, what would be its approximate location. If the character of the country permit, he travels on horseback, though usually it is necessary to go on foot, in which case he is accompanied by one or two packmen. His equipment need consist only of an axe, a pair of field glasses, a notebook, a hand-level or two barometers, and a pair of steel climbers to enable him to climb a tree with facility. By climbing a tree he will often be able to obtain a good knowledge of the country, and to take such general observations as may be of use in the preliminary survey. He must estimate distances and elevations, or obtain the latter by means of the barometers or hand-level, make notes as to the courses of rivers and streams and their crossings, establish the general direction of the chains of hills, locate passes, look out for water communication or some other way to obtain access to the different parts of the line, so as to facilitate the forwarding of supplies, and, in short, acquire the greatest amount of knowledge of the country in the least possible time. Upon his report depends the

PRELIMINARY SURVEY,

the party for which should consist of a chief, a transitman, two levellers, two rodmen, a topographer, one or two picketmen, two chainmen, five axemen for the line and one for each levelling party, three to six or even eight packmen, and sometimes a commissariat officer and an explorer.

In most preliminary surveys, the duties of the various officers are substantially the same. The instructions of the Chief Engineer of the Canadian Pacific Railway to the Staff may be taken as a general illustration of their character. The gentleman placed at the head of a party is required to take general charge of it, and is held responsible for the execution of all instructions, as well as for the maintenance of proper discipline in the party. Every member of the party is under his charge and must obey his orders. In conducting the survey, he is expected to be at its head every day, exploring in front and to the right and left of the line, in order to see what obstacles may be encountered and, if they are serious, decide what is the best manner of avoiding them. When he finds it necessary to leave the party, or in the event of illness, he should nominate the person to act in his place for the time being; should he fail to do so the transitman should take charge.

The duty of the transitman is to run the instrument, to keep the notes, and in case there is no topographer, to take the topography.

The duty of the first leveller is to make a profile of the line and cross-sections; that of the second leveller is to check the bench-marks and to assist in cross-sectioning.

The principal duty of the other members of the party is to obey all orders with diligence and to the best of their ability.

Before starting the survey the transit should be set up over the terminus and a true north and south line determined by means of an observation of the pole-star. To do this, place the instrument at zero, choose some well-marked point, set the cross-hairs upon it a little before dark, and see that no one disturbs the transit until time for the observation, the hour for which may be found in the Nautical Almanac. It is usual to observe the star when at its greatest eastern or western elongation, but it may be observed when at its maximum depression below or elevation above the pole if the instrument is provided with a tangent screw to produce a slow motion in a vertical plane. When observing the star at its greatest elevation or depression, which can be ascertained by keeping the intersection of the cross-hairs on the star, being careful never to pass it, and noting when it appears to cease rising or falling, no correction is required. The reading of the horizontal circle is the angle that the line from the terminus to the point chosen makes with the true north. In observing the greatest elongation, keep the vertical hair on the star and note when it appears to cease changing its azimuth, then take the reading, which will be the angle that the above-mentioned line makes with the vertical plane through the star at its greatest elongation. The correction for this angle can be found by a very simple rule given in the Nautical Almanac, and is to be added, if the star lie between the pole and the line, and to be subtracted if it does not. Should the line lie between the pole and the star, this will give a negative result, which shows that the angle so obtained is to be laid off from the pole towards the star: *i. e.,* if the elongation be east, the bearing given by the minus angle will be east. It is easily seen that the latter method is by far the better, for it is necessary to use only the horizontal tangent screw (the one which gives the upper motion, of course), while in the former both the horizontal and vertical screws have to be turned at the same time. Having found, then, the true bearing of a fixed line, the true bearing of the initial line of the survey can be easily ascertained by measuring the horizontal angle between the two lines.

Suppose the party all ready to start and the initial bearing taken. The axemen go ahead clearing the line and the chainmen follow, firmly driving stakes about three feet long and two by two inches in section at every hundred feet, numbering them consecutively with red chalk as they go.

When it is necessary to move the instrument, on account of the distance of the picketman, who has been keeping the axemen on line, or because of a sudden rise or fall of the ground or a desired change of direction, the transitman gives the signal previously agreed upon for "hub," the picketman chooses a convenient spot for setting up and finds "point" on the line into which one or two of the axemen drive a stake from four to six inches in diameter, and from one to six feet long according to the quality of the ground, and the picketman finds "point on hub" into which he drives a nail.

The transitman then sets the back picket, which in bush work is a small, straight sapling whitened on one side, with a cross-piece eight or ten inches long held in a cleft near the top, moves his instrument to the new hub, over which he sets up, sights to his back picket, reverses his instrument and starts the axemen and chainmen to work. Before giving hub again, the transitman should sight once more to the back picket in order to satisfy himself that his instrument has not been moved, and if uncertain of the adjustment, should turn the instrument around 180° by means of the lower movement, sight to the back picket, reverse, and give "second point on hub." If this coincides with the first one the instrument is in adjustment, if not, then the distance between the two points (measured, of course, at right angles to the line) must be bisected accurately and the nail be driven at the point of bisection. This is, in fact, performing the second adjustment of the transit. Beside each hub, at a distance of about three feet, should be driven a large stake called " hub-stake," five feet long, at least five inches in diameter and squared at the top. On it should be written the *exact* chainage of the point on hub, and the distinguishing mark of the survey party, which is usually one or two letters. In setting up in swampy ground, "legs" or long heavy stakes should be driven flush with the surface of the ground, in order to provide a tolerably firm "set up" for the instrument. The plumb-bob should be brought *nearly* over the nail by driving down first one leg and then another, then moving the feet of the tripod until the point of the plumb-bob exactly covers the nail. If the instrument have a shifting head much time and trouble will be saved. Hubs should be placed at the summits and bases of hills, so as to avoid as much as possible chopping brush and moving the instrument. At intersection points the hub-stakes should be marked " apex," and the angle to right or left should be written on another of the squared faces. The best kind of a hub is the stump of a tree that comes directly on line, for it cannot be knocked out of place. In running through comparatively level country it is well to keep to the low ground as much as possible without lengthening the line greatly or making it too crooked.

It is to be remembered that the survey is not final, hence that it is best not to turn out for a small ridge, but to go over it and take a cross-section on its summit to where it tails off. When trying to reach a summit, it is necessary to follow approximately the contours of the hills so as to obtain a gradual rise. In hilly country where the line rises and falls in long stretches, the best way to proceed is to follow up a stream to near its source, then cut across the divide and follow down another stream on the other slope. If the banks of a river are high, a good crossing can often be found by going up stream, where they are usually lower. In crossing a lake on the ice soundings should be taken, as it might be found desirable to drain the lake.

Offsets usually are taken at right angles to the line, but sometimes inclined. Short ones can be turned off quickly by standing on the centre line, stretching the arms at full length along the line, then bringing them suddenly together; with a little practice a right angle can thus be turned very accurately. For long distances it is necessary to use an instrument of some sort, a crosshead being as good as any. Offsets are made to locate the bases of hills and the edges of streams. Traverses of ridges or rivers are most easily made with the compass, provided there is no local attraction, by setting up at every alternate station and reading the bearing of both lines intersecting at that point. The compass is sometimes used on the main line in level country where there is no great local attraction. Very often no instrument is used at all, except at the angles, the long tangents being run in by pickets. It is surprising with what accuracy work can be done by the compass and pickets in a comparatively level country.

As running a picket line in the bush is a very different affair from what is taught at the R. P. I. during the chain survey, it may be well to describe the operation. The pickets are thin, straight saplings about five and a half feet in length, sharpened to a long, fine point at the top, and at the lower ends for pushing into the ground. The tops of two of them are set on line about fifty feet apart by the instrument; a third is then set about fifty feet farther on, the top being brought exactly in line with the others. A check on the work can always be obtained by glancing back alone the line and ascertaining whether the last three or four pickets are in one straight line. A pair of field glasses is of great assistance in picketing.

To "tie on" to an old line, set a hub on each side of it, drive a nail in each along the line of sight of the instrument, and stretch a string tightly between the nails. Next take up the instrument, set it up on the old line, and in its direction, and sight to a picket moved along the string until covered by the vertical hair; then drive a hub and set a nail at the point thus found.

The levellers commence work after the transit party has made a good start, and they should never approach the transit closely enough to disturb the back picket. If the second leveller find a difference of more than one-tenth of a foot between benches, the levels should be rechecked. The speaking-rod is almost exclusively used in bush work; it is much better than the target-rod for rapidity, and the leveller is not at the mercy of his rodman, who may often be too ignorant to read the rod. Care should be taken to equalize backsights and foresights, and neither should exceed four hundred feet for accurate work. It is possible to read an ordinary rod on a clear day at eight or nine hundred feet, but one cannot rely on levels so taken. The best kind of level for rapid work, as far as my experience goes, is the Pastorelli. It is fourteen inches in length and has a ball-and-socket joint, by means of which it can be set up in places where it would be impossible to use an ordinary Y level. The telescope being inverting may cause a little trouble at first, but it does not take long to become accustomed to it. The best kind of rod is a piece of well-seasoned pine wood sixteen or eighteen feet long, four inches wide and one and a half inches thick at bottom, three inches wide and three-quarters of an inch thick at top, and divided into tenths and half-tenths. The form of level-book should be that shown in the figure below:

Sta.	B. S.	Int.	F. S.	H. I.	Elev.	Remarks
....	....	....	....	....	....	....
....	....	....	....	....	....	....
....	....	....	....	....	....	....
....	....	....	....	....	....	....
....	....	....	....	....	....	....
....	....	....	....	....	....	....

The F. S. column is for *turning points alone,* so that by adding up the B. S. and F. S. columns, subtracting one from the other, and comparing the remainder with the difference in elevation of the starting and final points, a check on the accuracy of the book may be obtained. Bench-marks should be made about every fifteen hundred feet, and should be well defined so as to catch the eye readily. The ordinary method of making them is to blaze the side of a tree or stump, drive a nail into a projecting knob on the root, and write the elevation of the top of the nail, together with the distinguishing mark of the survey party, on the blazed part. The exact location of the bench should be noted in the level-book in the column for remarks. To make a good bench-mark without the use of a nail, slice off the side of a stump to very near the bottom, and bring the remaining part to a rounded apex.

The leveller should note every stream and river crossed, its size, direction, the elevation of the surface, the difference between the elevations of high and low water, the velocity of the current, the probable discharge, and any peculiarities which it may seem to possess. While in the field it is not necessary to work out the elevations of intermediates; it is sufficient to know the height of instrument and the elevations of bench-marks. Every evening the leveller should "make up" his book and plot the profile. Levelling can be done very rapidly in winter, as travelling on snowshoes is so much easier than ordinary walking in the bush. The uncertainty as to the shape of the ground beneath the snow sometimes makes it difficult to set up the level satisfactorily, but if the three legs of the tripod be kept vertical and the snow be well packed about them, the instrument will be kept as steady as in any ordinary set-up. If the rodman carry a three-foot stake to be pushed through the snow to the ground and support the rod at intermediates, much time may be saved. When this stake is used care should be taken to add three feet each time to the reading of the rod. The transit book ordinarily used has one page ruled into squares, each side representing one hundred feet, and the other page ruled for remarks, a red line running through the centre of each. In case there be a topographer in the party, the transitman need make note only of the chainage, magnetic bearings and deflection angles, being sure to state whether they are to right or left. But if there be no topographer, it will be necessary for him to keep full topographical notes of offsets to the right and left, wherever they are necessary, contours of hills, courses of streams, the quality of timber and soil, the location of ridges and lakes, and similar matters.

The first entry in a notebook each morning should be the name of the person acting as transitman, leveller, or topographer, as the case may be. All notes should be clearly and distinctly made in pencil on the spot; no additional notes should be entered with the original notes after the day on which the latter are written. Field notes should not be inked or changed in any way, but copies of them may be made in ink and reduced levels may be entered in ink. This is to prevent what is called "cooking" the notes, an offence of which no true engineer is ever guilty. Any man found tampering with the level notes or benches, or trying any scheme to make poor work pass for good, should get his discharge without any compunction on the part of the Chief Engineer or of those who are interested in seeing work well done. A plot of the day's work should be made every night and the latitude and departure should be computed.

Checks on the work should be made as often as possible. The check for deflections is made by taking an observation of the pole-star every ten or fifteen miles and comparing the reckoned true bearing with the observed, after making the proper correction for convergence. This is found as follows: Let n = the number of miles in a degree of longitude, a quantity depending upon the latitude of the place, then will 60 ÷ n = the correction in minutes per mile of longitude. Calling m the number of miles of longitude between the two points considered, 60m ÷ n will be the required correction. A check for the distance can be roughly obtained by ascertaining the latitude and longitude of various points along the line, by observations of the stars. Checks can sometimes be obtained by tying on to old lines. An error in the direction of the line may have been made by recording an angle to the wrong side; to ascertain if such be the case, divide the error by two and see if there be an angle on the plot which is equal or very nearly equal to this result. If there be one, the chances are that the mistake was made in that way. In case the error cannot be located, it will be necessary to go over the work again, commencing at the point where the next to last observation was taken. Errors are sometimes made in reading a deflection angle, and sometimes by making a crook in the line owing to the transit being out of adjustment or level. Whenever an observation of the pole-star is made, the variation of the needle should be noted.

As the survey progresses, the engineer in charge should project a location line on the map by means of the cross-sections taken to right and left in order to give a general idea of where the true location of the road will be. He is expected to keep a diary in which to note the progress of the work each day, the difficulties overcome, and everything of value relating to the survey. He should see that the camp is properly supplied with everything needed, and should, if possible, have depots for provisions made at points near which the line will pass, so as to avoid packing them over the line. Camp should be moved every three or four miles, in order to avoid long walks to the place of starting work in the morning. It may be necessary during the progress of the survey to forward special instructions to the engineer in charge; consequently, for this and other reasons, that officer should take especial care that whenever the camping ground is changed, a notice, containing the following information, be distinctly written upon a tree or in some other conspicuous position:

1. The distinguishing letter of the survey.
2. The number of the camp.
3. The date of removal of camp.
4. The probable direction and distance to the next camping ground.
5. The name of the engineer in charge of the party.

The success of the survey is materially assisted if each man endeavor to save as much time as he can. A few hints as to how this can be effected may be of use. Before moving the instrument the transitman should, if he wish to prolong the line, set two pickets on line *beyond the new hub,* in order that the axemen may continue their chopping while he is moving on and setting up. He can set his own back-picket, if it be left ready for him, by placing it close behind the instrument and bringing the cross to the level of the eyepiece. As soon as point for hub is called for, one of the axemen should commence making a hub, and if the ground require it, legs for the instrument. The fore-chainman who carries a light axe should busy himself by cutting stakes when not busy chaining.

There is a great variety of opinions as to what transit is the best for bush work. Some engineers prefer those of English manufacture, others those made in this country. The most satisfactory that I have ever tried is one of Gurley's manufacture.

LOCATION.

After the results of the different preliminary surveys (if there be more than one) have been handed into the office, it is there decided what is to be the approximate location of the line. The party for location is the same as for preliminary, except that no explorer is needed. The general style of the work is the same, the principal differences being that, as the survey is final, the centres are run in on the curves, and greater care is taken in getting the elevations of points between the stakes and on the cross-sections. The subject of curves is so well treated in Henck's Field Book for Engineers that it is useless to go into it here. It will be sufficient to state that the formulæ most often employed are $T = R \tan \frac{1}{2} I$ and $C = R \tan \frac{1}{2} I \tan \frac{1}{4} I$, where T is the sub-tangent, R the radius of the curve, I the angle of intersection and C the crown distance. The latter is used as a check for the correctness of the first half of a curve which is so long that several changes of instrument are required. The number of stakes put in at one setting-up depends upon the natural features of the ground, the degree of the curve, and the size and thickness of the timber. In running around a rocky bluff it may be impossible to see more than one hundred feet at a time, especially if the angle of deflection be large; in which case it would be well to put in stakes fifty feet apart.

In Plate I, Fig. 1,* suppose the transit to be set up at B to run in the curve BCDEF, etc., from the initial tangent AB. If the points C, D, E, and F are all to be located from the point B, it will be necessary to clear out all the timber on the area included between the chords BC, CD, DE, EF, and FB. Now if the curve be easy, that is of light curvature, say thirty minutes, that area will not be great, hence it would ordinarily take less time to clear off the timber than to make a new set-up at D. In this case the areas of the triangles BCD and DEF only would have to be

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* See insert at the end of this paper.

cleared. If the curve were heavy it can easily be seen that time would be saved by making the two settings-up. Before commencing the chopping, the transitman decides how many stations he will lay off and sets a picket on each extreme chord BC and BF (in the case taken above) at a short distance, say twenty feet, from the instrument, to serve as a guide for the axemen. One slight difference between laying out a curve in the field and the explanation for doing it usually given in text-books should be noticed. In text-books the first chord is taken to be one hundred feet, while in practice it very rarely occurs that a B. C. (beginning of curve) comes at an even station, so that the first chord is nearly always less than a full chain, and the first deflection angle will be equal to the difference between the chainage of the B. C. and that of the next full station divided by one hundred and multiplied by one-half the degree of the curve; for example, if the chainage of the B. C. is 1021 + 54.6, and if it is a three-degree curve, the first deflection angle will be $\frac{(1022-1021+54.6)\times 1^\circ\ 30'}{100}$ $= \frac{45.4 \times 1^\circ\ 30'}{100} = 0^\circ\ 40'\ 52''$ nearly, or in practice 0° 41′. The second angle of deflection will be 2° 11′, the third 3° 41′, etc. If the length of the curve be 925 feet ($= 100\,I \div 3^\circ$), the chainage of the E. C. (end of curve) will be 1030 + 79.6, the last chord will therefore be 79.6 feet long and the corresponding deflection angle, or increase of deflection angle as the case may be, will be $\frac{79.6' \times 1^\circ\ 30'}{100} = 1^\circ\ 11\frac{1}{2}'$. By 1030 + 79.6 is meant 1030 chains and 79.6 feet; it is always written thus on the hub-stakes. The degree of a curve should be made as small as possible, for the longer the curve the shorter the line. The "lay of the ground" nearly always decides the degree of curvature to employ in connecting two tangents, that curve being chosen which will give the best profile or in case of a choice between rock and earth excavation, *the least expensive line,* the limiting value of the degree of curvature, of course, being never exceeded. This limiting value and that for the grades were decided upon at the same time. Where the grade and a curve occur together, a resistance to motion is caused by each, hence the limit of the former must be so decreased that the resultant effect shall not exceed that due to the maximum grade on a straight line. It has been found experimentally that a one-degree curve causes as much resistance as a 2.4 feet rise per mile, hence the limiting value of grades should be reduced by that amount for every degree of curvature. The value 2.4 was found for a speed of twenty miles per hour.

Locations are sometimes made by taking the angles and distances directly from the plot and laying them out upon the ground, but the ordinary way is to use the plot simply as a guide, and to run in the tangents and put in curves to fit. In going around a rocky shore the intersection points often fall in the water, as shown in Plate I, Fig. 2.* To run in the curve FC, run the random lines AE and ED, measuring the angles BAE $= i$, GED $= i_1$, and HDK $= i_2$, then LBD $= I = i + i_1 + i_2$. In the triangle EAD, EA, ED and the angle AED are known, so that DA and the angles EAD and EDA can be computed. This will give the angles BAD and BDA, so that in the triangle BAD the sides BA and BD can be found. After deciding upon the degree of the curve, the sub-tangent can be calculated in the ordinary manner, the differences between this distance and the lengths AB and BD be laid off from the points A and D, and the curve run in as usual.

If several location lines have been run in the same neighborhood, the stakes on the one adopted should be painted, so as to catch the eye readily.

CONSTRUCTION.

The first steps to be taken after the final location has been decided upon is the clearing of the right of way. The width of clearing should be about one hundred and thirty feet, in order to allow for high banks and wide side-ditches, and for the erection of a telegraph line, which should be placed on the berm, or space between the foot of the slope of the bank and the side ditch, and always on the same side of the line. As a wide clearing is necessary to prevent trees from falling on the wires, the centre line of the road should not pass through the middle of the clearing, but far enough to one side to allow the telegraph line to occupy that position. Assuming the average fill to be three feet, the width of the top of the bank seventeen feet and the slope ratio of the side one and a half horizontal to one vertical, the slope stakes would extend thirteen feet from the centre line of track which would be fifty feet from one side of the clearing and eighty feet from the other, and the telegraph line would occupy the centre of the clearing. If a high bank or a deep cutting cause the telegraph line to be brought to near one side, the clearing should be widened there; and in any case, all trees which in falling would strike the wires, should be cut down. The trees felled on the clearing should be windrowed and burned, and any logs left by the fire should be hauled into the bush or be burned a second time. When the line has been properly cleared, *and not until then,* the section engineer should commence operations.

His first duty is to lay out the off-take drains. His next is to re-establish the centre line, for most of the stakes and perhaps some of the

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* See insert at the end of this paper.

hubs will have been destroyed during the clearing. While doing this he should reference all hubs at the beginnings and ends of curves, and on tangents at least one in every two thousand feet, and at apices in the grade, in order to facilitate the finding of the centre line after the grading is finished. The ordinary method of referencing is to turn off an angle of 45° to the tangent, set a hub at 100 feet, driving a hub-stake beside it with R. H. marked thereon, reverse the instrument, and place another in the same manner; then turn off an angle of 45° to the other side of the tangent and proceed as before. Should the natural features of the country or any other cause prevent setting hubs on both sides of the line, it will be necessary to set two hubs on each reference line, as shown in Plate I, Fig. 3.* Care should always be taken that the hubs are placed in positions where they would not be liable to be disturbed. I have employed the following method and prefer it to any other, although it was not in accordance with the instructions given to the section engineer of the road on which I was working: Set up the instrument over the hub to be referenced, turn it until two trees are found on line with the hub, and cut down the most convenient one close to the ground, so that the instrument can be set up over the stump. After having clamped the plate, set a nail on the stump, then reverse and set another on a blaze upon the other tree. Turn the instrument at about right angles to this reference line, find two other trees on line and proceed as before. By this means the hubs are set so permanently that even fire will not destroy them. Their positions should be accurately noted in the field book.

The next step should be to run over the levels very carefully, placing benches at every thousand feet on the edge of the clearing most distant from the centre line, so that they will be out of the way of the graders. Benches should always be placed at both ends of heavy cuttings for easy reference in driving grade plugs during the progress of the work. Where the line does not pass through wooded country and no convenient object can be found for a benchmark, one should be made by sinking a post in the ground five or six feet in order to be below frost and marking the elevation of a nail driven in the top of it upon a stake placed alongside. Plugs two inches in diameter and six or eight long should be driven at the foot and directly in front of each centre stake. They should be made level with the surface of the ground, and the levelling rod should be held upon them when levels are taken. Should the plugs not be driven to the surface, it will cause a large discrepancy between the actual quantity of material excavated and that called for by the profile. If the section engineer would like to avoid all chance of receiving an overhauling from the office on account of such a discrepancy, he can do so by clearing away from the foot of each stake all moss and spongy material and driving the

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* See insert at the end of this paper.

plug down to solid ground, thus recording the true level of the base of the embankment, for all such material is compressed to almost nothing by the weight of the superincumbent earth. This may be unnecessary labor, but it is well to look ahead a little, especially if those in charge of affairs are at all inclined to be unreasonable.

After the profile of the line has been drawn on profile paper to scales of 200 feet to the inch horizontal and 20 vertical, the gradients should be carefully established, so that long hauls and irregularities in the continuous grade line are avoided and so that cuts and fills are as nearly equal as it is judicious to make them.

The next thing to be done is to write the cuts and fills on the centre stakes, at the same time setting the slope and ditch-stakes. To set the former when the ground does not slope greatly, add together (for earth cuttings and embankments) one-half the width of road-bed (ordinarily 11 feet for cuts and 8½ feet for fills), the centre cut or fill, and half the latter quantity; measure off the distance so found at right angles to the centre line, *estimate* the rise or fall in that distance, add to or subtract from the distance three halves of the rise or fall, and hold the rod at this new distance. The level having been previously set up and the height of instrument above grade determined, sight to the rod, subtract the reading from the height of instrument, and add to it one-half the width of road-bed and one-half of the quantity itself. Should the sum thus obtained equal the distance of the point, where the rod is held, from the centre stake, set the slope stake there; if not, try again until the two quantities agree within two or three tenths of a foot. Set the ditch stake outside of the slope stake at a distance equal to the width of berm, which varies from six to fifteen and even twenty feet, according to the stability of the material, the most common value being ten feet. On the slope stakes should be marked S. S. and their distance from the centre line; the ditch stakes should be marked D. In grading side ditches it is a good plan to drive a plug four or five feet outside of the ditch stake and mark on the latter the cut below the former.

While the slope stakes are being set, elevations should be taken on every cross-section at distances less than the semi-width of the road-bed, and wherever the slope changes; they should be taken, too, at some distance beyond the ditch stakes. Cross-sections should be taken and slope stakes set wherever the slope of the ground or the grade changes. Cross-sections should be set out instrumentally at right angles to the centre line on tangents; and on curved portions at right angles to the tangent of the curve.

The levels on the cross-sections should be taken in the same manner as those on the longitudinal line, commencing on a benchmark, and using the same datum; they should be continued through a series of cross-sections till another benchmark is reached, on which a level should be taken to test the accuracy of the work.

Grade plugs should be driven at the ends of cuttings, where the grade cuts the natural surface, both on the centre line and at a distance on each side of it equal to the semi-width of bottom of cutting. Driving a grade plug where the grade is level is quite an easy matter, for it is only necessary to have the rodman hold his rod at different points until it reads an amount equal to the difference between the height of instrument and formation level; but when the grade is rising or falling, the change in the height of formation level must be taken into account every time the rodman moves the rod in the direction of the line. It is sometimes customary to drive, at the ends of large cuttings, grade plugs two or three feet long and as many inches in diameter, the upper end being bound with an iron ring so as to be useful as a rough reference during the course of the work. The form of level-book used on construction differs somewhat from that used on the preliminary survey, and is given below.

Sta.	B.S.	Int.	F.S.	H. I.	Elev.	Grade	Cut	Fill	Remarks
	3.26			1128.30	1125.04				B. M. No. 23
1320+55		11.21			1117.09	1116.55	0.54		Grade 1 per
R. 11		10.20			1118.10	1116.55	1.55		100.
R. 14, s.s.		9.80			1118.50	1116.55	1.95		
L. 8.5		13.20			1115.10			1.45	
L. 13.5 s.s.		14.40			1113.90			2.65	
L. 30		16 80			1111.50				
T. P.			0.28		1128.02				

The notes here given show .the centre levels and the cross-sections taken together, as would be the case were the benches run in by flying levels. In setting slope stakes in swamps it is not necessary to use the instrument; simply set them at the distances called for by the fills marked on the centre stakes, allowing a little for the subsidence of the surface, if it be thought advisable.

Before commencing to work a cutting, the quantity of material in it and its quality should be determined, so as to decide how much should be carried each way, and to ascertain how far it will complete the embankment at each end, due allowance being made for the shrinkage of the material.

The ground is now ready for the contractor to set the graders to work. He should commence operations at the ends of the off-take drains and continue these across the right of way to the opposite side ditch, in order to start four gangs of men in each large depression of the line at building the embankment from the side ditches. While the embankment is being built, both the contractor and the engineer should keep an eye on the graders, especially if they are doing piecework, so as to see that the close cutting and grubbing are properly attended to, and that no poor material, such as roots, moss, or logs, is thrown in the bank. Unless it be very large the embankment should be kept higher in the middle than at the sides all through the progress of the work, and when finished the upper surface should be rounded off so as to fall from four to six inches from centre to sides. It should be left considerably above grade, so as to allow for subsidence, the amount being determined by previous experience.

By the term "grubbing" is meant tearing the stumps out by the roots, and by "close cutting," chopping them down nearly level with the ground. Grubbing should be done in the off-take drains, in side ditches, on embankments under two feet in depth, and in light cuttings, though it is not often paid for in borrow-pits or where the cutting exceeds three or four feet. Close cutting should be done in embankments over two and under five or six feet in depth. "Never to allow a stump to reach within two feet of grade," is a safe rule, for the grade may some time be lowered if the bank should sink uniformly below its original elevation. It costs more to chop one projecting stump out of the bank than to close cut a dozen before commencing the grading.

Before opening an earth cut, the engineer should see that the side ditches are finished as far as the embankment will extend, and that the material excavated from them is cast into it. In shallow cuttings it is sometimes necessary to excavate below grade in order to remove all the loose surface material, and to fill either with ballast or firm earth taken from a deeper portion of the cutting or elsewhere. All large stones and boulders measuring less than 27 cubic feet, and all loose rocks that may be removed with facility by hand, pick, or bar, without the necessity for blasting, are classed as "loose rock." All stones and boulders measuring more than 27 cubic feet, and all solid quarry rock are classed as "solid rock." In cuttings composed of both earth and solid rock, a berm six feet wide should be left on the upper surface of the rock. Owing to its removal, earth shrinks from eight to twenty-five per cent. of its volume, loose rock changes but little, and solid rock occupies one and a half times the space in embankment that it did in its natural state. Earth cuttings and embankments have slopes of one and a half horizontal to one vertical; rock cuttings, one horizontal to four vertical; and rock embankments one to one. Where the side ditches and line cuttings do not furnish enough material for the banks, borrow-pits are rendered necessary. To lay one out, fix a line far enough from the pit not to be disturbed by the excavation, and divide the surface of the ground that is to be removed into squares whose sides are parallel and perpendicular to the line of reference, then take the elevations of the corners of these squares above the datum used on the line. After the borrow-pit is finished, relocate the corners of the squares and take their new elevations. This divides the volume removed into vertical prisms with square bases, whose length can be found by averaging the differences of the two elevations taken at each corner. If the length of the sides of the squares be taken equal to some multiple of three feet, the calculation of the cubical content will be greatly facilitated. Thus if the length of each side is thirty feet or ten yards, the horizontal section is one hundred square yards. If the average of the differences of elevations at the four corners of any square is twenty-seven feet or nine yards the cubical content of the prism will be nine hundred yards.

Station grounds should be laid out, if possible, on long tangents where the grade is nearly level, or at least does not exceed nineteen feet to the mile. If it is necessary to place one on a curve, let the station-house be situated near the apex, to permit the station-master to see trains approaching both ways. Clearings of eight or ten acres should be made about station-houses to provide against danger from bush fires, if for no other purpose.

Very unstable swamps or muskegs are occasionally crossed by the method called "logging," which consists in placing logs transversely to the line under the bank, leaving their ends projecting at least six feet beyond the bottoms of the slopes. When this is done, the ground must not be broken for the side ditches.

Sloping ground covered with pasture should be ploughed to prevent the embankment from sliding after it is built.

Measurements of material removed should, whenever possible, be taken in excavation, and when taken in embankment, due allowance should be made for both shrinkage and subsidence of the natural surface. Preliminary estimates are made from the profile by averaging end depths; quantities in ditches are taken out by the method of "end areas"; and in cuttings, by either the last mentioned method, or by the "prismoidal formula," which is represented by the equation $V = \frac{l}{6}(A + 4M + B)$, where V is the cubical content, l the length between the sections, A the area of one cross-section, B that of the other, and M that of a cross-section which is not measured on the ground. Its value can be obtained by reducing each end area to an equivalent area between parallel bases by the formula $h = \frac{1}{3}(\sqrt{6A + b^2} - b)$, where b is the width of road-bed and h the depth of the equivalent area, and calculating the area corresponding to the mean of the two depths thus found. It is sometimes obtained by calculating the area of an assumed cross-section, all the variable dimensions of which are taken to be a mean between the corresponding dimensions of the two end sections. The following example will serve to illustrate the different methods mentioned.

The easiest way to calculate the area of a cross-section, whose dimensions are given, as in Figures 4, 5, and 6, Plate 1,[*] is to add together twice the centre depth and the depth at each side of the road-bed, multiply the sum by the width of the latter and divide by four. Then multiply each of the side depths by the horizontal distance of the slope stake from the side of the road-bed, add the results together, divide by two, and add to the quotient the area first found. By so doing there will result in this case, $A = 479$ sq. ft., $B = 147$ sq. ft., and $M = 291.5$ sq. ft. (from diagram). By the rule first given, M would equal 295.4 sq. ft., which shows how closely the two methods agree.

If $l = 100$,
By mean depth.................. $V = 1072$ cubic yards
By end areas.................... $V = 1159$ cubic yards
By prismoidal formula, 1st case... $V = 1116$ cubic yards
By prismoidal formula, 2nd case... $V = 1106$ cubic yards

The method of end areas always gives an excess, and the method of mean depths a deficiency. An average of the two in this case gives 1116.5 cubic yards, which agrees almost exactly with that obtained by the prismoidal formula—this is merely accidental, it being due, perhaps, to the similarity of the sections. On uneven ground cross-sections ought not to be taken far enough apart to make the area of one more than double that of the next. In Henck's Field Book can be found formulæ for many special cases of earth measurement.

The office work of a section engineer comprises the making of a working profile and plan, and the filling out of a section-book, cross-section sheets, and return sheets. On the profile the final gradients should be drawn in red and the surface of the ground in black. It should be completed by drawing black vertical lines at every 100 feet, on which should be written in black figures the height of the surface of the ground above datum, as ascertained by the levels taken on the plugs; immediately above these should be placed the formation level in red figures; the height of fills should be placed below the surface-heights, and the depth of cuts above formation level. Cuts and fills having been ascertained by subtracting surface and formation levels, the one from the other, should be written in black figures. At each change of gradient, the vertical lines should be in red and the height of formation level written in the same color, but with larger figures than at the intermediate stations. Where side ditches occur they should be indicated by blue lines at the level of their bottoms, and the centre depth of cutting should be marked in blue figures on the black vertical lines. At the bottom of the profile should

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[*] See insert at the end of this paper.

be shown in blue the curves in the line, with the stations where they begin and end and their degrees of curvature; and at the top should be indicated the quality of the timber and ground, stream and road-crossings, culverts, and similar matters. In preparing plans, all *existing objects*, such as roads, buildings, and fences, should be drawn in black lines; water should be indicated by a blue tint; and works *to be constructed*, such as deviations of roads and streams, the centre line of the railway, and the limits of land required for railway purposes, should be shown in red lines.

The section-book should be filled so that it will form a complete and accurate record of all the longitudinal and transverse measurements and levels. In the upper portion of each page should be entered, in the proper place, the chainage to every station and intermediate point on the centre line; each change of gradient, with its rate of inclination; the height of surface as well as formation level at each station and intermediate point; and the corresponding depth of cutting or filling. On the lower part of the page every cross-section should be regularly entered; the distance on each side of the centre line, and the height above or depth below formation level should be given, and the slope-stakes should be designated. Tables of bench-marks and reference hubs should be made at the beginning of the section-book. Cross-sections are plotted on paper ruled into squares for the purpose, each square representing one foot, and their dimensions and areas should be marked on the plot.

The return sheets, which are large, should be ruled horizontally and vertically, and an account of all material moved or used on the section up to date should be kept on them. The vertical columns, which are of varying width according to what is to be written in them, should contain the following quantities (with others if need be), though not necessarily in the exact order here given: Stations from and to, clearing, close cutting, grubbing, line cutting, side ditches, borrow-pits, off-takes, catch-water drains, rip-rap, masonry, stone drains, pole drains, piles, lumber, ties, timber, and totals. The divisions of line cutting, side ditches, and off-takes should each be subdivided into three columns for earth, loose rock, and solid rock; borrow-pits and catch-water drains into two each, for earth and loose rock; piles into two, for amount delivered and amount driven; and the timber into as many as there are different sizes used on the work. Grubbing, close cutting, and clearing are measured by the acre; earth, loose rock, solid rock, rip-rap and masonry by the cubic yard; stone drains, pole drains, piles, and timber by the linear foot; ties by number; and lumber by the foot board measure.

Before making out the first return sheet, the line should be divided into groups so that the cuts and fills will come in separate divisions. For instance, if the chainage of one end of a cutting were 1628 + 43 and the beginning of the next were 1640 + 64, the division, which would be for a fill, would be made from the first mentioned chainage to the last, and the quantities recorded would appear in the columns marked side ditches, off-takes and perhaps borrow-pits. If the chainage at the end of the second cutting were 1648 + 20, the division would include all between station 1640 + 64 and that station, and the quantities recorded would appear in the columns of line cutting and catch-water drains. When some of the divisions would thus be rendered too long for convenience in keeping the accounts, it will be necessary to sub-divide them, taking, if practicable, the chainage of some natural or artificial feature of the ground, such as a stream, or a culvert opening as the point of division. The column for totals should be divided into three parts, for earth, loose rock, and solid rock. It is filled by adding up the quantities of each kind of material in each horizontal line, and entering the sum on that line in its proper place. After all the columns are filled, add them up vertically and place the sums so obtained on a horizontal line below the columns, each in its proper place; then adding the total amounts of earth, loose rock, and solid rock in this horizontal line (excluding those under the total columns), the amounts obtained should equal those found by casting up the total columns. To find for what the contractor is to be paid, subtract from each of the totals the totals taken from the last return sheet. Thus the exact amount of work done and its distribution along the line may be readily determined by examining the return sheet.

Many of the directions here given for the manner of doing the office work are taken with very little change from the instructions given to the staff on the Canadian Pacific Railway; but as the officers of that road have devoted a great deal of attention to that subject, I think you will find their methods to be as good as those used on any of the railways on this side of the border.

After the grading has been completed and the ties have been distributed, the engineer relocates the line on the grade very exactly, using a thin picket and driving thin stakes (laths turned edgewise will do) at every hundred feet. Near the stations he also drives grade-plugs very accurately to the height of the rails.

To ballast the line the ties are laid and the rails spiked to them so that the train can be run slowly over the road for the purpose of distributing the ballast. In unloading, the train must be kept working to and fro so as to mix thoroughly the different qualities of ballast, until a sufficient quantity is deposited for the first lift. The track must then be raised so that there will be an average depth of six inches beneath the sleepers, and the ballast must be well beaten and packed under and around them. As the raising proceeds the end of the lift should extend over not less than three rail-lengths, and before trains are allowed to pass over the inclined portion of the track it must be made sufficiently solid to prevent bending of the rails, or twisting the rail joints. A second lift is afterwards put on in the same manner. In wet cuttings an increased thickness of ballast is often necessary. All soil should be stripped from the surface of the ballast pits, and no material whatever should be placed on the road-bed but good clean gravel, free from earth, clay, loam, or loamy sand. The maximum size of gravel is three inches in diameter, and larger stones should not be used.

A good deal more could be said on the subject of "construction," but as I mentioned in the beginning of these lectures, it is not my intention to write a complete treatise upon railroading, so I will refer you for further information to the works of Vose, Henck, Trautwine, and Gillespie. However, as some of you may sometime go into contracting, I will close with a few remarks on that subject.

Railroad contracts are let sometimes by the mile, but more often by the cubic yard and other dimensions. To make a successful bid it is necessary to have a very good knowledge of the country through which the line is to pass, so as to be able to estimate the cost of plant, labor, and materials. The usual form of tender indicates the probable amount of each kind of material, and the bids are based on these quantities. If the person bidding feel positive that any of these quantities are in excess, and any others in reduction, he can, by bidding low on the former and high on the latter, keep down the sum total of his tender, and yet, if it be accepted, run a good chance of making a reasonable percentage. On large contracts it pays to send an expert over the line so as to ascertain pretty definitely how to bid. Care should be taken in purchasing supplies and plant for the work: a great deal of money can be saved by knowing how and when to buy. Attention should be paid to the transportation of supplies, getting them in sufficient quantity when the rates are low, so as to tide over the time when they will have risen. It does not often pay to sub-let a cutting, owing to the expense of working it; if any one can make anything out of a cutting the contractor himself ought to be able to do it. But ditch work is entirely another affair. Men are unwilling, as a general rule, to undertake such disagreeable employment as ditching, unless they see a good chance of earning big wages. A grader will take out nearly twice the quantity of material per diem when working for himself as when he is paid by the day; hence it is worth while for a contractor to sub-let swamp work to gangs of four or five, in which case it is well to make a written agreement with the men, binding them to do good work and to finish within a certain time. To insure the completion of the job, hold back ten per cent. of their pay until they finish everything satisfactorily. Never pay by bank measurement, for the navvies will be sure to fill up the bank with logs and stumps. A common trick of theirs, especially in winter when there is snow on the ground, is to pile about six inches of moss along the edges of the ditches so that when the measurements are made with a tape and rod, the depths will be in excess. In working wet cuttings it is often necessary to corduroy the road-bed, both in the cutting itself and on the dump, to prevent the carts from sinking axle-deep in the clay. If the engineer is good-natured, he will allow the ties to be used for the purpose, for it does them very little harm, and saves a great deal of expense.

The best way to take out loose rock is by means of simple sledges, which can be made very cheaply by bracing across two of the spreading roots of a large tree; no cheap, artificial joint could stand the stress that comes on the pointed end of the sledge. It is often cheapest to take out the gullet of a cut first; if this be done it is advisable to allow a slope ratio of one horizontal to four vertical, so that if rock be struck there will be no difficulty in giving it the proper slope. Contractors sometimes find it to be economical to waste the material from cuttings where the haul is long and the allowance for extra haul is insufficient to cover the extra expense. Loose rock is often hauled to the mouth of a cut and there wasted, the contractor substituting for it, at his own expense, an equal amount of earth. Rock cuts should be made the full width and depth as the work progresses.

In contracting, make your own measurements, not so much to keep a check on those of the engineer as to pay the workmen by, and to enable you to know the cost of all the different portions of work.

It is customary for contractors to keep a store for the purpose of supplying the workmen with everything they need for the work. If they are not carefully watched, the men are liable to overrun their account, and, as they express it, to "jump the job."

When sub-letting a piece of work containing loose rock, it is better to bargain for a lump price than to pay so much for one kind of material and so much for another, because an ignorant man is never satisfied with his measurements, in any case, and naturally counts upon a larger percentage of rock than he is likely to get.

No matter how scarce workmen may be, it is always good policy to discharge a mutinous man; it keeps the rest upon their good behavior; and it is for the best interests of all concerned to keep liquor sellers away from the line.

All the men on the work should be cautioned against removing any stakes, benches, or other landmarks of the engineer.

It is necessary, on a contract of any size, to keep plenty of plant on hand, especially such small articles as nails, bar-iron, horseshoes, picks, shovels, and irons for carts. On this point I can speak from experience, for once, when in temporary charge of a five-mile contract, I had to make a journey of one hundred and forty miles, half of the distance on foot, PLATE. I.

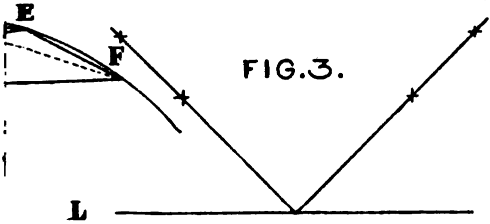


FIG. 3.

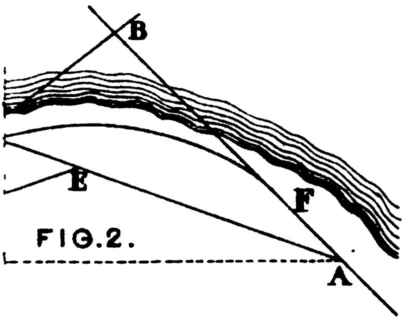


FIG. 2.

FIG. 4.

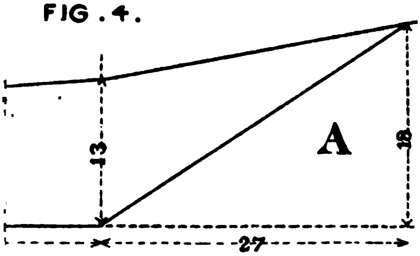


FIG. 5.

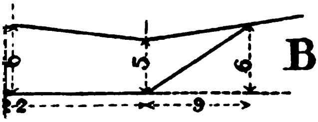
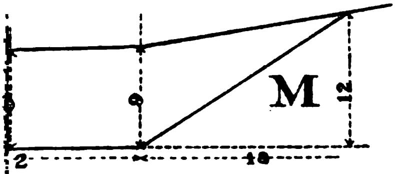


FIG. 6.



through the swamp in order to purchase a few horseshoes, nails, and axle irons, and had to have them packed thirty miles over the line. They were pretty expensive by the time they reached their destination. In contracting, as in everything else, it is better to do work well in the first place. One loses in reputation more than he saves in pocket by doing scrimp-work; besides, in the end, he may have to expend far more for repairs than it would have cost in the first place to complete everything according to the terms of the contract.

NOTES ON RAILROADING.

By H. P. Bell, Can. Pac. R'y.

Under the head of railroading a valuable paper appeared in the April issue of this magazine.* Speaking of the engineer's equipment for an exploratory survey the author says: "It need consist only of an axe, a pair of field glasses, a hand level, or two barometers, and a pair of steel climbers."

If the distance over which the exploratory survey is to extend be greater than the author of this paper seems here to contemplate, it will be found, in most cases, better to equip as follows: One hand level, one ship's sextant, one chronometer, one good pocket compass, one epitome of navigation, and one book of mathematical tables—barometers optional.

In keeping a traverse or track survey with lateral sketching, it will be found useful for after reference to fix a number of points by observation. Not all engineers understand well how to use a sextant, and a few hints may be useful. Never assume the index error as constant, but try it before each observation. Always correct, if necessary, with the key the adjustment of the horizon glass, and every night that a star can be seen, see that the optical axis of the long telescope is parallel with the plane of the instrument. Do not observe without using the long telescope, as a good contact cannot be otherwise made. Get a canvas cover made for the sextant box. Take one tin plate from the cooking outfit, and use this with a little water and a piece of Indian ink to make an artificial horizon. Carry the plate under the canvas cover on top of the lid of box.

The explorer can stop either in the morning, or more conveniently in the afternoon, and having worked his latitude by dead reckoning from the last mid-day observation, he can take the time at the place by observation, and work up his longitude just as at sea. Tree-top sketching by the aid of the hand level and compass will soon make an explorer very independent of barometers, whose results, with the greatest care, are sometimes very uncertain. If the distance of survey be short, and any sort of map in existence, a smart explorer, by the aid of a sextant, without a chronometer, can make a chart of his work so true that he can always feel his way over the same ground again in any direction, and strike or avoid well-defined points, as desired, with preliminary line. I will omit reference to all those portions of Mr. Waddell's paper as unexceptionable, until he begins to describe the work of the levelers on preliminary line, in which he states that they should never approach the transit closely enough to disturb the back picket; and I would remark in this connection, that in overcoming great differences of level it is sometimes necessary to run grade upon a side hill for many miles continuously.

In such a case it will be better to put the leveler tight up to the back chainman, the chainman close to the axman, and the transit behind. The chief of the party can turn the angles with pickets as the leveler calls out to him how he is going by grade, and the transitman can make a traverse through the chopping. As the leveler marks his relation to grade frequently

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* Van Nostrand's Engineering Magazine.

on the stakes, the back leveler or topographer can take note of that, and cross-section its amount out to grade, so that it may be possible afterwards to trace on the plan a complete contour line in the plane of the grade. In running grade on a side hill, the tendency will be to exaggerate the true length by preliminary line about ten per cent., so that if it be desired to locate a grade of one foot on the hundred, it will be best to run a grade of 9-10 of a foot per 100 feet on the preliminary line. Coming to that part of the author's paper in which he states his preference for a Pastorelli level, I would say (as the result of practice with many different kinds of levels) that the instrument made by Spencer & Sons, Grafton street, Dublin, mounted upon an American tripod, head, and legs, with only three screws in the parallel plate, will please almost any man. I would prefer the Y, as improved, to the dumpy, for the reason that the Y adjustments more combine theory with all the excellence of adjustment practically possible, than the other form of level. I say three screws in the parallel plates, because a plane will coincide with each one of any three points, in any position, but not with each one of four.

Further on, the writer makes the remark that leveling can be done very rapidly in winter, as traveling on snow shoes is so much easier than ordinary walking.

This requires explanation. It will be easier in certain places and at certain times. In other places and for long periods it will be easier to walk five miles in boots in summer than to break your own tracks for one mile on snowshoes. Further on, the author says of the transitman that if there be not a topographer, the transitman must keep full topographical notes, either side of the line by offset. Experience has proved that in a bush country the transitman who does this will consume more of staff and axmen's time than would pay for two topographers, and, therefore, for economical reasons, in a close country topographers are a sine qua non.

Passing on to that portion of the author's paper in which he speaks of recording an angle to the wrong side, it may be remarked that this is quite possible, if the transit book be kept on the right and left angle principle, probably the most dangerous known. But if all angles be read from the meridian, which is done practically by keeping the back reading on the plate when the instrument is moved forward, the chances of error will be infinitesimally small. Otherwise, take one of Gurley's transits divided in four quadrants and full circle besides. Grind off the variation so as to make the needle read zero when the plates are set at zero on the true meridian. Read the line bearings on the quadrant, and full circle besides, then look at the needle after. The chances of error will be reduced to the lowest point, and the probability of discovering an error, should one be made, will be raised almost to certainty. Many men dislike this system as involving too much work, but it saves time in the long run, and those who have used it never regret.

Further on the author of the paper referred to says: "Locations are sometimes made by taking the angles and distances directly from the plot and laying them out on the ground, but the ordinary way is to use the plot simply as a guide, to run in the tangents and put the curves in to suit."

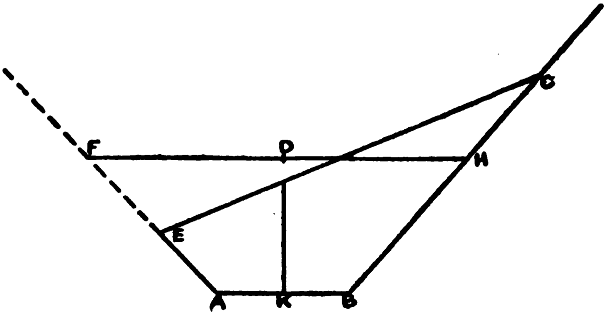
There are many cases on record where men have had to do a certain amount of work in a certain amount of time, the time being regulated by the provisions on hand and the means of transport. Under these circumstances it is often best to run the center line in at once, without going to apex. There are other reasons. If the timber be extra heavy, much time will be lost in chopping that may be saved by doing all this after the line is cleared and the first marks burned and obliterated.

By taking frequent offsets to the trial line, and having a tracing of the work as laid down in his pocket, the engineer can, by careful attention to simple American rules, keep his line in position (provided he does not make angular errors) without running to apex.

If he suspects an error let him take an observation at once.

Passing on to that part of the author's paper where he treats of the method of calculating quantities from cross-sections for construction, it is noticeable that he omits the calculation of quantities for a contract estimate altogether.

As there is often little time to spare over this kind of work, I will try to describe a method of estimating excavation of cuttings and cubes of embankments, introduced by me on the Intercolonial Railway in 1869, and on the Canada Pacific Railway in 1874. It is merely a modification of the method set forth by Mr. J. C. Trautwine in his earthwork tables, depending on the projection of a supposed level surface line, whose vertical ordinates, from grade to new or supposed surface, would produce the same quantities found by calculation from dimensions on sidelong ground. Having plotted the necessary preliminary cross-sections from field notes, these are to be equalized by parallel rules to equivalent area under level surface as follows:



Let ABCE be a cross-section of a cutting; produce the slope EA indefinitely; assume any point F by guess, a little over the center; lay the parallel ruler from C to F, move to E and mark H—join FH.

If now the line FH be horizontal, or even nearly so, DK will be the proper height to transfer to the profile at the point where prism is situated. Having so equalized all the cross-sections and produced a new surface line with supposed level cross-section, the quantities may be taken from tables.

If FH be not nearly horizontal, assume a new point F and repeat the process. If the surface line itself be crooked, proceed, first, by rules for equalizing a crooked fence, and afterwards as above directed.

Using this equalized surface line with a set of diagrams made for the particular bases in use, to show the number of feet in length for each successive yard in depth that it takes to make 100 cubic yards, the quantities may then be taken from the profile by measurement and inspection with a speed and accuracy incredible to those who have not seen it done.

The writer of the last month's paper refers to ditching. I may say of this class of work that the assistant engineer who can keep an orderly record of borrow ditching, that is cut and re-cut at all manner of irregular distances, shapes and odd times, has kept probably the most difficult class of work in order known to engineers, especially if it be in soft ground, liable to changes of form from drainage, pressure, and other causes. It is a mistake to suppose that the heaviest kind of work is the most difficult to manage or to measure. On the contrary, there is no work more easy to keep track of than plain line cuttings and borrow-pits in solid ground.

COMMENT.

The foregoing paper deals with but a limited portion of the field of railway construction and leaves many important topics untouched, but, within its range, gives a clear exposition of the major problems. Many larger subjects, such as tunneling, bridging, retaining walls, and protection from swift streams, are not discussed at all, but their importance justifies their exclusion from a lecture on field-work, as that term is commonly used.

Much of the work of exploration is now carried on in the office instead of the field, for the maps published by the United States Geological Survey afford the means of making a rapid examination of the country to be traversed by the proposed railway. They enable the engineer to see at a glance the general direction of the watercourses and ridges and to select with reasonable accuracy the most promising routes. Though these maps are drawn on a very small scale, the contour lines are approximately correct and make it possible to prepare rough estimates of the work of construction.

These surveys have, as yet, covered only a small portion of this country, but the maps have proved of great service to the engineers of the railways in the territory for which they have been prepared and published. In the West, in the northern and western portions of the Dominion of Canada, in Mexico, and in other new countries, the old method must of necessity obtain for many years to come. Great labor and often hardship fall to the lot of the engineers who make the exploratory surveys in these newer territories, but the work calls for a high order of engineering skill and good men will always be eager to undertake it.

There will, of course, always be differences of opinion regarding the value of surveying instruments, but the great value of the aneroid barometer for obtaining approximate elevations in rough country is beyond question. Where the country is easy to traverse and changes in elevation are not too abrupt, the hand level is a very satisfactory instrument; its results may be recorded directly, and it is not affected by temperature or weather; but where the changes in elevation are rapid the use of the aneroid is decidedly advantageous, and, if the work be done by two observers carrying compared instruments, good progress can be made.

In exploratory work, however, the instruments used are of far less importance than a knowledge of wood-craft and geology, well-trained powers of observation, and that ability which is obtained only by experience to judge from visible, natural features, the trend of country beyond, ability which is almost instinctive in the backwoodsman or mountaineer. Native wit, resourcefulness, courage, and a good physique are also essential, if the distance to be traversed be great.

The engineer who makes the exploratory survey should be thoroughly experienced in every phase of railway engineering and fully acquainted with the ideas of the road's projectors regarding the relative importance of reaching the various towns situated in the country to be traversed, and with the resources of the country, and should know how far the company's finances make it advisable to sacrifice a desirable route in order to obtain low first cost of construction. His work greatly influences the broad, general plan of the road, and bears directly on its success or failure; hence, before beginning the work, he should obtain every possible bit of information relating to the country and to the company's plans and should make himself master of the situation.

The work of the engineer in charge of the preliminary survey is much more restricted in scope. From the data furnished by the exploratory survey the general course of the road has been chosen, though it may possibly require two or more preliminary surveys to choose between routes for portions of the line. The preliminary survey is made at the least cost consistent with obtaining full information, for its chief purpose is to gather the data from which to prepare approximate estimates and determine the final location. Yet the work must be done with reasonable accuracy, or the information it furnishes will be misleading.

Good organization is essential to speed, economy, and thorough work. The duties and degree of authority of each member of a party should be clearly defined in advance, for any misunderstanding of these will cause confusion and ill-feeling, and will soon destroy all discipline. The chief of the party should keep the work well mapped out in advance or each man will be retarded by the one in front of him and the whole work will make slow progress. The party should work as a unit with military precision and should do just the work necessary to serve its purpose and no more. Too great attention to detail will add little to the value of a preliminary survey, but will greatly increase its cost.

The chief of the party cannot be too clear and thorough in his instructions, for, if they are faithfully followed, they will relieve him of much detail and provide time for him to obtain that broad view of the work which is essential to good judgment. To plan his work well and be ready in his decisions will inspire in his assistants the confidence and energy which are requisite to the best results.

The plotting should be kept close up to the work, so that errors may be detected and rectified at the earliest possible moment, for if an error should make it necessary to cover much ground a second time, there is not only increased expense and loss of time to be considered, but the irritation and annoyance and consequent loss of *esprit de corps* as well.

If the physical comfort of the men is not well cared for, if they are permitted to feel that for any reason their burden is unnecessarily increased, their effectiveness will be greatly reduced, their minds will be distracted from their work, and delay and error will result. Hence the party's camping equipment should receive careful and constant attention.

The locating survey is practically the preliminary survey confined to the one route finally chosen and amplified by giving close attention to the many details which were formerly sacrificed for the sake of speed. The contracts for construction are based upon the results of this survey, hence the information must be full and accurate. Meagre data will force the contractors to protect themselves by bidding high, while incorrect data will give rise to expensive and vexatious disputes.

Especial attention should be given to the field work relating to important crossings. The borings necessary to obtain the profile of the crossing should be made with unusual care, for erroneous information regarding the character of the bottom, such as mistaking a stratum of boulders for solid rock, may completely alter the method of sinking the piers and lead to the adoption of uneconomic span lengths. Especial care should be taken to obtain full information regarding the amount of water passing when the stream is at extreme flood, so that, in bridging, the waterway will not be unduly restricted. When a wide valley is to be crossed on a steel trestle, full information regarding the material available for embankment is desirable, for several times in the editor's experience it has been found possible to construct a permanent embankment for less expense than the trestle would have involved, though the locating engineer's information made the trestle appear advisable. If the valley is liable to overflow, however, the construction of an embankment with the consequent reduction of the waterway is dangerous both to the railway and to the property above. Each year brings a list of disasters due to impeded or restricted waterways, embankments and bridges carried away, shops and mills shut down and damaged, and business brought to a standstill along precipitous streams.

When construction begins the work should be well planned and the large questions all settled, but the task of the engineer is then by no means finished. The resident engineer needs tact, judgment, and firmness for his dealings with the contractors, a thorough comprehension of the details of construction, and at least a fair knowledge of the operation of a railway. The instructions issued by the chief engineer will, if they are full and explicit, lend him support and aid him in solving the problems which come up from day to day, but he must, in the majority of cases, act on his own judgment and knowledge.

It is customary for the railway to purchase a right-of-way of uniform width, except where yards or stations require more property, though the width should be increased in direct proportion to the depth of cut and height of embankment. If the right-of-way is too narrow a deep cut cannot be protected on the high side by a ditch, as it should be; the side ditches are restricted in size; and in both cuts and fills the slopes are made steep in order to leave room for the ditches. The foot of a slope should be constructed on a radius of about ten feet and the ditch should be so far away from it that it will not be filled by the wash from the embankment. Many railroads have been constructed with plane slopes, as though a slope would always remain a plane surface, a form easy to measure but impossible to maintain. In such cases the cost of maintaining the drainage and keeping the embankment full at the top is always excessive. And in the majority of such cases the bad construction has been forced upon the engineer by the penny-wise policy of purchasing a uniform and narrow right-of-way.

Banks should be sodded as soon as possible. The sod will obviate, or at least restrict erosion, prevent the growth of weeds, and present a sightly appearance. If it be possible to cover the slopes before sodding with rich soil saved from the cuts, or borrowed for the purpose, a good growth will be assured and much expensive renewing will be saved.

Horizontal as well as vertical shrinkage of embankments should be allowed for, otherwise the slopes will become concave instead of convex. Vertical contraction may be corrected by raising the embankment, but fresh material added to the sides to rectify horizontal shrinkage will be washed away very readily.

Embankments should be built in layers out to the slopes from the base up in order to obtain even settlement. To build up the center first, then widen the bank by dumping over the sides, is economical of both material and labor, but produces concave slopes which are not well compacted and which, consequently, will readily wash away. The best material should be placed in the center, where the greatest load falls. At bridges and diversions where the embankment is liable to extraordinary wash, it should be widened two feet or more, depending upon its height, and for at least two hundred feet from a switch about three feet should be added on the side next the stand in order to make it easy for the brakeman to catch his train after turning the switch. Inexpensive provisions of this character prevent costly accidents.

Where an embankment is subject to erosion, it should be well protected by rip-rap. Metal for this purpose may often be saved from the material forming the embankment. The slope should preferably be two to one. In sand or loam it is advisable to plant two or three rows of willows close to the water's edge, for they soon produce a mass of roots which offer very effective resistance to erosion.

Upon completion of the grading the embankment should be dressed to exact sub-grade, ready to receive the track. Then the grade stakes should be set on both sides of the track, level with the top of the rail, and so far from the center that the ballast will not disturb them. On curves the stakes should be level with the top of the inner rail, for this rail is kept at grade and all elevation of the outer rail is above grade. Grade stakes should be set one hundred feet apart on tangents, and fifty feet apart on curves. Point of curve, point of tangent, point of compound curve, and the beginning, the end, and the quarter points, at least, of the transition spirals, should be marked by stakes. If stakes are not set to grade, their elevation above or below grade should be plainly marked on them.

The leveling to grade, or to grade plus a predetermined allowance for settlement, should be done by the grading contractor before he leaves the work, for any portion of it which is left for the track-laying gang will be done at undue expense. The final dressing can best be done by a separate gang of workmen, however.

On the older roads the construction of the track is commonly turned over to the maintenance-of-way department, but on new work the constructing engineer generally completes the work. If the new track exceed from fifty to one hundred miles, the track-laying machine is generally employed, but the greater amount of new work is still laid by hand. The machine is economical of both time and expense if the country through which the line passes is rough, swampy, or wooded, but on flat, open country, track can be laid more rapidly and at no greater cost by hand.

The track-laying machine consists of a flat car from which two lines of rollers forming ladders, one on each side, are suspended. These ladders project well forward and, with other ladders which are supported on brackets attached to the flat cars on which materials are brought forward, form two lines of rollers, continuous from one end of the train to the other. The ties are pushed forward on one side, the rails on the other, by hand, and delivered to the workmen who place them in position.

If the track-laying machine is not used, the ties are hauled forward and delivered along the embankment by wagon, while the rails are brought forward on push cars. The ties are placed in position by hand, about sixteen per thirty foot rail on straight track and eighteen per rail on curves, and their ends brought in line. The rails are then placed in position, care being taken to keep the joints opposite each other, or opposite the middle of the parallel rail if the track is to be laid with broken joints. The gage is applied, a few spikes driven, and the car or machine moved forward, ready for the next rails. When the curvature exceeds two or three degrees, a machine is used to curve the rails.

When the track is in position the ballast is brought on in dump cars from which it is distributed by gravity, or on flat cars from which it is removed by a plow drawn along the top of the cars. The plow can be used while the ballast train is in motion. Some modern dump cars also are designed to be dumped while in motion, thus securing an even distribution of the ballast.

On first-class track grade is generally two feet, including six inches crown, above sub-grade, thus providing about twelve inches of ballast below the ties, but on branch roads and lines of lesser importance this distance is often reduced to fourteen inches and the crown omitted, thus leaving only six or eight inches of ballast below the ties. Indeed, on a great many of the cheaply constructed western roads ballast is entirely lacking.

The track should be raised to grade, both sides at once, in two lifts. The ballast should be well tamped under and around the ties, while the track should, at the same time, be carefully lined.

To handle the track-laying crew so that the work will be done rapidly, economically, and well, requires foresight and executive ability of a high order, for the work is congested at one point and materials must be brought forward and the empty cars returned over the same track, while the maintenance of the completed roadway is in a large measure dependent upon the care and skill exercised in placing the ballast and bringing the track to grade and line.

AN ADDRESS

DELIVERED BEFORE THE

MEMBERS OF THE KOGAKU KYOKAI.

INTRODUCTORY NOTES.

The address to the Kogaku Kyokai (the Japanese Engineering Society), though delivered a few months before Dr. Waddell left Japan, is in the nature of a farewell, for he had already arranged to sever his connection with the University at the end of the scholastic year. It is devoted almost entirely to the status of the professional work in Japan, and its chief interest lies in the glimpse it affords of the primitive conditions existing only twenty years since in the kingdom which has advanced from the civilization of the Middle Ages to that of the twentieth century within the memory of men now living, and in the broad view of the economics of the country.

It is not surprising that a nation which was hedged about by exclusive laws for centuries should be far behind the rest of the world in many respects, but it is astonishing that, even for important economic reasons, a people so nice in their manners and customs and so resourceful in most respects should tolerate offensive and unsanitary methods of the disposal of wastes. To support a large population on so small an area of arable land undoubtedly demands the greatest economy, but Japanese knowledge of horticulture and agriculture is of the highest order; and it is not borrowed knowledge, since much of it is peculiar to Japan; consequently, it is difficult to understand why such offensive methods of waste disposal should continue in use.

That the value of an abundant supply of pure water was not generally understood is not so surprising, since many communities in our own country are still indifferent to it.

The improvements which have been wrought since Japan began to learn from the Western world are marvelous. She has sent out thousands of her brightest youth to be educated in Europe and America; she has employed American and European instructors for Japanese institutions, and she sends her best trained men to the West to acquire a thorough knowledge of what we are doing in education, in pure science, in agriculture, in manufacture, and in engineering. She is searching the earth for its wisdom and skill and is making excellent use of the knowledge gained. She has already accomplished great things in agriculture and agricultural chemistry, and the time is near at hand when she will take her place with the Western nations in the development of new ideas in the sciences, in engineering, and in manufacturing.

Dr. Waddell's address gives a brief but clear view of the status of engineering in Japan twenty years since, while the great amount of descriptive matter published since Japan became a first-class military power shows what position the profession occupies to-day. The advancement is undoubtedly far greater than Japan's most sanguine friend could have hoped for, yet improvements are following each other with great rapidity, as the constant purchase of modern machinery in this country clearly indicates.

In mineral resources accounts agree that Japan is deficient, but there can be little doubt that she will not be slow to take a hand in the exploitation of the vast, undeveloped resources of the continent of Asia. Then she will produce her own steel and iron and other engineering materials, construct her own bridges, buildings, and machinery, and take advantage of her proximity to obtain a satisfactory portion of the trade with China.

Japanese business methods and her ideas of business integrity are still quite oriental, to her detriment, but she will not be long in learning that it is to her advantage to adopt stricter ideas of commercial responsibility.

The intelligence, energy, and ability of the Japanese are of the highest character. Their progress has been marvelous, and the nation will undoubtedly occupy an undisputed position in the van at a very early date. This intellectual and material advancement should be especially gratifying to those Europeans and Americans who have spent time in the service of the Emperor and measurably assisted in the nation's development.

TO THE MEMBERS OF THE KOGAKU KYOKAI.

GENTLEMEN: You have invited me here to-night to deliver an address upon "Engineering Matters"—at least that was the subject given me by your committee. The breadth of such a topic would generally deter me from attempting to speak thereon; but, under the present circumstances, it is of all others the theme that I should have chosen; for, being about to leave this country after a stay of nearly four years, there are many things concerning engineering in Japan about which I would like to give an opinion, in the hope that some of my suggestions may be the means of effecting improvements.

But before entering upon the subject, allow me to thank you most sincerely for the honor which you conferred upon me at your last meeting by electing me honorary member of your society. It is a courtesy which I appreciate now, and which I shall appreciate in future years, when your association will have become the representative Engineering Society of Japan, as the Institution of Civil Engineers is of England, and the American Society of Civil Engineers is of the United States of America. This election to your society on the eve of my departure from Japan is most gratifying to me, in that it proves that the Japanese engineers as a body recognize at least my honesty of purpose in writing the Memoir, which has met with such bitter opposition from certain British engineers resident in this country.

In that Memoir I criticised a certain class of Japanese structures designed by foreigners: to-night I am going to give you my opinion concerning other classes of engineering work that are more purely Japanese, hoping that both you and the other members of our profession in this country will take what I say in good part and will recognize the disinterestedness of my motives and the true reason for my making these remarks.

As my object is to indicate methods by which you can improve the engineering practice of this country, there is no need for me to dwell upon the good work of which so much has been done by Japanese engineers, especially in connection with the railways, hence we shall confine our attention this evening to other matters.

Among the principal branches of engineering in this and other countries the most important are those which relate to transportation; because without good facilities therefor no country can be very prosperous commercially.

Of the various avenues of transportation in Japan none are so neglected as the common country roads, which at certain seasons are often all but impassable, and never are in what may be considered a satisfactory condition. The trouble has been and to a great extent still is that the building and maintenance of these roads are not left to engineers, but are entrusted to subordinate officials, who have not been educated for such work. Some of the roads are so bad that one is almost tempted to believe that their builders had studied all the correct principles of road making for the express purpose of violating them. Instead of raising the road-bed above the natural surface of the country and avoiding cuttings wherever possible, they have dug it from one to three or four feet deep, making the road act as a drain for the surrounding country. Not content with attracting as much water as possible to the road, they have endeavored to keep it there by planting close alongside rows of trees with thick foliage, or dense bamboo groves that most effectually keep off both sunshine and wind, the two great natural maintainers of good roads. Too often, even on the better class of roads, the side ditches are not made large enough, are allowed to fill up, or are omitted altogether.

In building new roads I would advise that, whenever practicable, they be raised a foot above the natural surface by excavating material from the ditches; that no trees, bamboos or shrubs be allowed to grow on the south side of any road near enough to cast a shadow on it between the hours of 10 a. m. and 2 p. m. on the shortest day of the year; that no houses be built closer to the outer edge of the nearer side ditch than forty feet; that on the north side of the road no trees or bamboos be allowed to grow within fifty feet of the outer edge of the nearer side ditch; that the surface of the road slope both ways from the centre line with a moderate fall; that the depth of the side ditches be about a foot and a half to two feet; that the side ditches be graded with a level and rod so as to carry all the water to the off-take drains; that these be properly made so as to draw off immediately during the heaviest rainfalls all the water in the side ditches; that the surface of the road be properly metalled, when funds are available; and that the roads be repaired constantly by dividing them into sections and placing each section in the care of a properly trained laborer.

In improving the existing country roads I would advise that those portions of them which are sunk much too far below the level of the natural surface be abandoned; that all trees, bamboos, and shrubs which cast a shadow on the roads be ruthlessly cut down; that no houses be built nearer to the side ditches than forty feet; that a certain time be allowed the residents to move back houses that are too close to the road; that a proper system of side ditches and off-take drains be dug; and that the roads be kept properly repaired.

Anyone who has traveled from Utsunomiya to Nikko or from Tochigi to Nikko will agree with me in my statements concerning the bad condition of some of the Japanese roads.

Within the last three or four years I have noticed a great improvement in the streets of the Tokyo-fu, but outside the city the condition of the roads is very little better than it was when I first came to this country.

The city streets of the Kyoto-fu are in a wretched state, owing to the fact that large unbroken stones are employed for surfacing.

There is a little peculiarity in the method by which some of the streets of Tokyo are kept in repair and to which I would like to call your attention. Before putting on a new coat of gravel the old surface which has become very hard, though uneven, is broken up to a depth of four or five inches. This is not only a waste of labor, but is also injurious to the new surface. The old surface should be merely scratched with picks so as to make the old and the new materials bind.

I cannot too forcibly impress upon you the necessity for having good common roads throughout the country. They will pay for themselves in two or three years. They will prove equally advantageous to the people of the country and to those of the towns and cities, increasing the load per vehicle or per man at least three-fold, and reducing greatly the market price of country produce. By their means the prices at which Japanese produce and manufactures can be delivered at foreign ports will be so reduced as to enable the people of Japan to compete with those of other countries in lines hitherto untried. For military purposes good roads in connection with a complete railroad system are essential, and their existence would reduce the necessary size of the standing army to one-half, thus lowering the taxes for the maintenance of the army and adding to the *producing* population.

Concerning the building and maintenance of country roads I cannot do better than to quote from Engineering News the following in reference to the roads of Henry County, Ohio:

"Our roads can be very materially improved at an expense entirely within the means of even this tax-burdened people. By all means let us have stone roads as soon as possible; but, first let us prepare a place to put the stone, to insure us against the chance of losing it in mud unfathomable. For the sake of illustrating, let us suppose that we are going to make an entirely new road. After the road is located we will stake out the track, which should not be more than twenty feet wide. After this is done, let a competent and trustworthy civil engineer stake out two lines for tile drain, each a few feet from the centre line of the road-bed. These tiles should be laid to a perfect grade; not less than an average depth of three feet and carried to the nearest outlet, no matter what the distance nor what the expense. This is an absolute necessity, as without efficient tile drainage there can be no good road built in Henry County, either of stone, gravel or any other material that is accessible. After the tile are laid as above directed, proceed to raise the roadbed about fifteen inches in the centre and eight or nine at the outside, by scraping upon it the surface soil. No clay should be allowed on the road. It should then be made perfectly even and smooth. No hillock or hollow should be allowed under any circumstances. It will then be a good plan to go over it several times with the heaviest rollers and make it as compact as possible. Then dig your side ditches with the same care as to grade and outlet as was done with the tile. These open ditches need not be deep, but should be so graded that no water will stand in them to soak and soften the bed of the road. They will carry off the water that falls upon the road while the tile will carry that which comes up from below.

"In order to keep this road in good condition, appoint a man to go over it every day in the wet season and draw off the water from puddles that may form on the bed of the road and fill them up, and also to keep the side ditches in good working order. The road should be completed as early as the middle of August, so that it may be well settled before the fall rains set in. Let the above principles apply to old roads. The roadbed need not be raised more than two feet above the general level unless in crossing a low place.

"After you have constructed your road in the above manner, you have a foundation upon which you may build your stone or gravel road, which you may delay doing until you feel able to bear the expense. When you wish to put stone on the road, make it twelve inches thick at the centre and six or eight at the side; the width should be from twelve to fifteen feet. This done you have a road that will be a pleasure to travel on at any time of the year. Farmers can then sell their produce when the price is most satisfactory.

"There are three prime essentials to road building in this locality. They are, first, drainage; second, better drainage; and third, the best drainage possible."

The retaining walls of this country till lately have been to me a matter of wonder and surprise. Built as they are of vertical rows of single stones shaped into truncated pyramids, how they stand has puzzled me beyond measure. The explanation of the phenomenon was made apparent a short time ago by a wall in Yokohama—and it is a very simple one, viz., that such walls *do not stand* for any great length of time. Their standing at all would upset any theory of earth pressure, if such a theory still existed. The practically instructed engineers of to-day, however, do not recognize the correctness of any of the theories of earth pressure—all have been tested and found wanting.

If any of you have occasion to design a retaining wall to resist earth pressure, I would advise you to turn to your "Trautwine's Pocket Book" and adopt the empirical rules there given. They are reliable to this extent, that walls proportioned by them and erected on firm foundations will not overturn, although it is possible that lighter structures might answer the purpose.

In respect to railroading I would direct your attention to the study of some better means for removing earth than that at present employed, viz., by hoeing or shoveling it into a rope mat, which is slung on a pole and carried by two men. Such a method cannot be economical. If man-power must be employed for removing the material, it would be much better to use wheelbarrows for short hauls, and carts or wagons on tramways for long ones. In America steam shovels are coming into use for even such small excavations as side ditches, when the material removed from them is employed for making the embankment. The time for using machine labor to such an extent as this in Japan has not yet come, but come it must, eventually.

The methods of pile driving still in use are rather crude and inefficient. The day has not yet arrived for the use of the steam hammer and water jet, but surely there are some intermediate ways that may be employed to advantage. In this respect I notice an improvement on the railway work.

In locating lines of railway along the valleys of rivers I note a proneness to cut into the feet of the side hills in order to avoid confiscating valuable rice land. There is no true economy in so doing, for the hills may develop a tendency to slide, as was the case between the Uyeno and Oji stations on the Nakasendo Railway; besides, embankments are far more satisfactory to maintain than excavations.

In regard to river improvements, I would suggest a thoroughly scientific study of the physics and hydraulics of the Japanese rivers, and the more effective protection from flood of the river-bottom farm-lands by levees. That the Japanese rivers are unusually hard to control there is no denying; consequently the subject demands even more careful investigation than is given it in other countries.

It is possible that in some parts of Japan the movable dams, which are becoming so common in Europe and America, may be advantageously employed for the improvement of river navigation. This is a matter that is worth looking into.

The highway bridges of this country are still rather primitive. One of the principal objections to them is the shortness of the spans, necessitating the use of so many piles that the waterway is often impeded to such an extent as to cause the destruction of the bridge by washout. This is a common mistake in new countries, and is due to false ideas of economy.

The best kind of road-bridge for any locality in Japan is rather difficult to determine. For cities, especially at the crossing of large rivers or rapid streams, I would in every case recommend iron bridges of the American type, such as I have investigated at length in my treatise on "The Designing of Ordinary Iron Highway Bridges," care being taken to make the spans long enough to prevent all possibility of washout.

For remote country districts perhaps the wooden Howe truss bridges are the best, though in America I would recommend them only as temporary structures in districts where iron is expensive and timber very cheap. The objections to this kind of bridges are that they are short lived, and that there is of necessity a great waste of material in the bottom chords. I noticed a neat little structure of this type near Tokorosawa on the road to Tokyo. It was designed by one of my former pupils. Although the web members would appear rather light to American eyes, the structure as a whole showed a careful study of detail and a proper appreciation of stiffness as well as strength.

A bridge properly designed in every respect for a small load is much better than one badly designed for a much greater load; therefore, if you must economize, it will be well to do so by adopting small moving loads, and designing your structures in all particulars according to scientific principles.

In America the combination Pratt or Whipple truss bridge, having the compression members of wood, the tension members of wrought iron, and the details of cast iron, is always better and generally cheaper than the Howe truss bridge. Whether this would hold true in any portions of Japan can be ascertained only by detailed calculations. By adopting standard sizes of bridges for various spans, importing and keeping in stock certain sizes of flat, round, and square iron of the required lengths, and having standard patterns for the castings, combination bridges ought to be manufactured cheaply and should prove very economical.

The timber should in all cases be well seasoned. This can be accomplished by having it cut and stored a year before it is needed. There should be no difficulty experienced in so doing, if the building of road-bridges throughout the country be left in the hands of competent parties, who will thoroughly systematize the work.

Concerning railroad bridges I have but little to add to what I have said in my Memoir, except to suggest that you give the system which I advocate a trial. There are two or three late improvements in American bridges which do not appear in the Memoir. One is the entire abandonment of bent eyes on rods: this will necessitate special pins for connecting lateral rods. These may either pass through jaws on the lateral struts or be attached to special plates riveted to the upper and lower sides of the chords.

Another improvement is the hinging of the batter brace at the shoe, so as to insure a uniform distribution of the pressure on the rollers or bed plate. This necessitates either the increasing of the sectional area of the batter brace or the hinging of the same at the middle of its length by a "collision strut," running to the first lower panel point. This strut, as its name implies, acts also as a safeguard against blows from unduly projecting loads on passing trains; but the latter object can be more effectively attained by planting very firmly in the embankment at the end of each truss a very heavy, well-braced timber pile at a distance of fifteen or twenty feet from the structure. It can also be accomplished by taking care that no cars be improperly loaded.

Some two or three years hence I will, if the authorities of the Imperial University desire me to do so, write an Appendix to my Memoir, in which will be clearly described all the latest improvements in the American method of bridge designing. There will be a new table of weights of iron per lineal foot, which will provide for all the changes suggested.

In respect to piers and foundations for bridges I have but little to say, except to suggest that you study all the foreign works on the subject and see for yourselves what method will be the best for any particular case. It does not appear advisable to use piles of unpreserved timber in salt or brackish water, which is usually in this country inhabited by the *teredo navalis*, as the bridge piers of Tokyo testify. The only effective preservative against the ravages of this sea-worm so far discovered is plenty of creosote oil injected into the wood. Unfortunately, this process is a very expensive one, especially in Japan, where creosote in large quantities is not to be had.

Concerning the subject of the preservation of timber I would refer you to some of the latest Transactions of the American Society of Civil Engineers, in which you will find the reports of a special committee of that society which has been systematically making investigations in this line for several years past.

If the adequate preservation of timber in this country against the ravages of the *teredo navalis* demand the use of large quantities of creosote oil, would it not pay to establish gas works in the principal cities, and manufacture creosote and other valuable substances from the refuse products? The gas would be of great benefit for lighting and heating purposes, also for operating gas engines, machines that are coming into great favor in America for purposes that require small power. Gas light in the last two or three years has been decidedly improved, owing to the competition of the electric light.

Next in respect to architecture; the people of Japan must judge for themselves whether houses built in foreign style and heated and ventilated according to the most approved system are a desideratum or not. They certainly are more expensive to build, but they last longer and are far more conducive to comfort than are houses of the purely Japanese style. Moreover, when built of brick or stone they are not so subject to conflagration, which is also a matter of economy. If the danger from fire were reduced, there would be more incentive to furnish your homes comfortably with the conveniences of modern life, including well-filled bookshelves.

In adopting houses of foreign style let me give you a few words of warning. First look well to the foundations, or the walls of your buildings will crack owing to unequal settlement. If I am not mistaken, such cases have already occurred in Tokyo. Second, look well to the drainage and to the thorough ventilation of the basements; otherwise, diseases will be engendered that will cause so much inconvenience that the benefits to be derived from the change will not be appreciated.

To express an opinion of any real value concerning the best system of sewerage for Japan requires more knowledge of sanitary engineering than I, or any other non-expert in this branch of the profession, possess. The conditions are peculiar. To leave matters *in statu quo* will not do, as anyone possessed of the sense of smell must allow; but what changes should be made is the question. The ordinary system of water carried sewage will not answer for two reasons: first, the excreta of the population are necessary for manurial purposes; and second, there is no adequate water supply. Perhaps, as I believe was suggested by Prof. Ewing, the excreta could be so collected in air-tight metal boxes and carried away at night as to remove the causes of such noxious odors as greet one everywhere in Tokyo. The garbage and horse manure of the streets can be removed as at present, but principally at night. But there is left the most noxious of all the disease breeders, viz., the filthy open or partially closed gutters that line the streets. Even on the steepest hillsides, owing to the roughness of the bottom and sides of these drains, the filth collects in them, and the stench it produces seems worse than that from the drains of the low-lying districts. Perhaps if these drains were properly graded and lined on bottom and sides with concrete finished off with a mortar of sand and cement, and flushed at intervals, either automatically by stored rain-water, or by pumping from the water mains, an improvement might be effected.

Unfortunately, it is not only in the cities that one encounters the vile odors of putrifying excreta. I have traveled mile after mile in the flat country districts without being able for a single instant to get this horrible stench out of my nostrils. Surely, this state of affairs must be prejudicial to the health of the inhabitants of the whole district where it exists. To breathe such an atmosphere day after day, night after night, for weeks at a time must certainly lower the tone of the constitution and render one unable to resist the attacks of malarial and other diseases. Is there no practicable way to deodorize and render inoffensive this abominable manure? If there is the law ought to enforce its use.

It would not be a bad plan for the government to engage the services of an acknowledged sanitary expert for three years to study the peculiar conditions of Japan in respect to this question, perhaps by making a few experimental systems of sewerage, and to make an elaborate report on them; then his recommendations should be followed to the letter.

Concerning the quality of the drinking water in Tokyo and the evils to be anticipated from using the present ancient system of water-works, several foreign employees of the government have already treated; hence upon these points it is only necessary for me to remind you of the results of their experiments and the deductions they made from them. Ere long you will have in operation in Yokohama a complete system of water-works, built according to the most approved European methods; and by the resulting advantages you will be enabled to judge as to the expediency of providing similar systems for all the important cities and towns of the Empire.

There is a large natural supply of energy which the people of Japan do not properly appreciate—I refer to the plentiful distribution of water-power. The energy of many large falls is entirely wasted, even in localities quite close to the thickly populated districts. Water-power in this country is used only on a very small scale, and even then wastefully. The efficiency of the existing water wheels in most cases could be increased from fifty to one hundred per cent. by designing them scientifically—and this at a very slightly increased first cost. The designing of water wheels with horizontal axes is left to carpenters, when it is really the work of engineers. With one exception it is better to purchase turbines abroad than to try to manufacture them at home; because, not only will the cost be less, but also the wheels will be more efficient and satisfactory. The exception referred to is the hurdy-gurdy, a wheel invented by a Californian engineer, to be used with high falls and small supplies of water. It is very well described in the Transactions of the American Society of Civil Engineers.

Concerning the designing of roofs I think that the Japanese have still something to learn; for it was only the other day that I read of the timber roof of a theatre failing under a load of snow and killing a number of people. Moreover, the iron roofs at the railway stations show a smaller amount of knowledge of detail on the part of the designers than do even the railroad bridges. In riding on the Tokyo-Yokohama Railway, have any of you ever noticed the connections of the sway rods which brace the supporting columns of the overhead foot-bridges at the stations? If not, take a look at them the next time you pass over the line. You will see a small bolt, about equal in diameter to the rod, passing through the end of the latter and through a small lug on the cast end of the column. If a split eye had been used, it would not have been so bad, although the diameter of the bolt should have been more than doubled. A symmetrical distribution of parts is one of the first principles in designing ironwork.

In respect to mining, it will be necessary for the Japanese to study economy in the extraction, reduction, and transportation of their products. if they wish to compete with other nations in foreign markets. It seems a pity that so many mining enterprises in this country should have proved failures. I believe that if their management and operation had been entrusted to foreign capitalists and trained mining experts, the mines could have been made to pay handsomely. My reasons for this opinion are based entirely upon what others have told me.

You, gentlemen, are probably all political economists to this extent. that you would like to see the tide of wealth flow towards Japan, and that you have often thought of ways and means of attaining this desideratum. Perhaps in some respects a foreigner's opinion may be a useful supplement to your own, in that he often looks at matters from a different point of view. Wealth can come in only two ways, from abroad in payment for the industry of the people, or by the fortunate discovery of rich mines of diamonds or the precious metals.

Judging from past experience any reliance on the second method would be misplaced; hence it is necessary to depend upon the industry of the population. Moreover, this industry must be properly utilized. It does not suffice that every man be kept busy; it is necessary that a large portion of the people be employed in preparing articles for export. That the people of Japan, especially those in the cities, are not employed in the most profitable manner is evident to anyone riding along the streets of Tokyo. The number of idle clerks huddled together over the *hibachi* is an indisputable evidence that too many men are employed to do one man's work, as are also the many idle jinrikisha-men that one sees everywhere. But, not even when they are exerting themselves to the utmost, do the latter perform what may be termed useful work, i. e., useful for the enrichment of the country. There is no true economy in employing men as beasts of burden. It is an acknowledged fact in America that in ninety-nine cases out of a hundred machine or animal power is ultimately cheaper than man power. Moreover, the use of the former leaves more hands to be occupied with useful work.

Again, look at the temporary character of many of the constructions in Japan—houses so flimsily built that the cost of repairs is greater than the interest on the difference in first cost between these and first-class buildings requiring comparatively few repairs for a number of years

—river improvements that necessitate renewals every two or three years—road metalling so scanty as to require annual or even semi-annual renewal—wooden bridges on pile foundations—do not these show a want of true economy?

But, for all this unprofitable employment of labor there is a reason, which, under the present circumstances, is not a bad one, viz., that the population of the country is great, and that the multitude must be kept at work. To abolish this useless expenditure of energy it does not suffice to pass laws enforcing the erection of better houses, prohibiting men from acting as beasts of burden, compelling the use of animal power, limiting the number of clerks in stores and servants in private houses; the remedy is to provide means for employing the surplus labor in a truly useful manner. This the Japanese government for years has been trying to effect, and with partial success. One great obstacle to the complete achievement of the desired object is that all enterprises are more or less under government control. The experience of other nations tends to show that government as a money-making corporation is not a success. Too many employees are required, and these have no incentive to extra exertion. If the government could leave the entire management of various enterprises in the hands of private individuals, it would be better. The great objection to doing so is that these individuals have not had sufficient business experience of the right kind. If foreign capitalists were allowed to settle and do business in Japan, and were given all the rights and privileges of Japanese subjects, a better state of affairs would be instituted at once. Paying manufactures would be established, and skilled labor would not only be encouraged but would be much better paid. The idea that these foreign capitalists would enrich themselves at the expense of the country, then carry away their accumulated wealth, is a fallacy. The money so accumulated would not come from Japan, but from abroad, and for every dollar thus carried away at least twenty more would have been brought into the country and left there.

An indiscriminate encouragement of manufactures in general would not be attended with success. The Japanese people are peculiarly adapted for certain kinds of work, and it is by attending to these and letting other kinds alone that the national wealth will be increased.

A tariff reform is decidedly needed—one that will admit duty free everything essential to the progress of the country, and will just suffice to prevent the importation of articles that can be economically manufactured at home. There should be also a high duty on luxuries. The reason for not putting a very high protective duty on articles that can be manufactured at home to advantage is that it would encourage monopolies. The opposite course, by limiting the profits of the manufacturers, would sharpen their wits and force them to invent and employ economical methods of production.

Another essential to commercial success is the encouragement of sound business principles among the contracting and merchant classes. To succeed in business one's word must be as good as his bond, and his bond must be adhered to as strictly as were the laws of the Medes and Persians. Many Japanese of the lower classes have no idea of the meaning of a contract. With them it is merely a thing to be broken in case that, by fulfilling it, they would be losers instead of gainers. They do not look ahead sufficiently. It is difficult for them to realize that by losing money to-day they may establish a reputation for business honesty that will bring them in money to-morrow.

Would it not pay the government to engage the services of a foreign capitalist, who has an acknowledged reputation not only for business ability but also for literary and scientific culture—an amateur political economist, in fact—to study the existing state of business affairs in Japan; give lectures on the management of business enterprises and kindred subjects, and write a number of small, elementary, and practical treatises on them for translation and sale among the business people? Such a man who would be willing to undertake the task would be hard to find; but there are such men in both Europe and America. Unfortunately, with them money is no object; therefore, it would be only through the reputation to be attained and the satisfaction to be experienced from the consciousness of having done a great and useful work for an ambitious and enterprising nation that one of them could be induced to engage in such an onerous undertaking.

How many of the laboring classes, especially in the cities, regularly perform a full day's work, and how many hours per day when working does the average laborer conscientiously attend to his duties? As far as I can judge, the answers to these questions are anything but satisfactory. It is another essential to national success that every laborer (and in the broadest sense of the term every man should consider himself such) perform regularly a full day's work of eight or ten hours. From the highest official to the lowest coolie this principle should apply. In Europe and America it is the lower classes who are hardest worked, but in Japan the opposite appears to be the case. The great and praiseworthy efforts of the instructed and cultured people of Japan constitute the first step to national greatness; nevertheless, they alone cannot raise the nation in respect to wealth and power to the level of the principal nations of Europe and America. It is upon what are ordinarily termed the working classes that reliance must be placed, and for this purpose these working classes should receive a *working* education.

These few ideas of mine on political economy may appear crude and elementary, for I am no political economist; but no man who goes about Japan with his eyes open can fail to form conclusions of his own on this subject.

While traveling in the country districts during the dry season I have been struck by the great waste of man-power in irrigating the fields with water raised from the ditches by tread-mills. Cheap wind-mills could perform this service most effectively, especially if small storage reservoirs were constructed on the higher ground in the neighborhood. Wind-power is the cheapest and most reliable of all the sources of energy, when the amounts required are small; and in utilizing this power the United States of America take the lead. The wind-mills of that country are light, cheap, effective, and capable of running almost automatically for long periods of time; consequently, it would be well for Japanese engineers to study the construction of these machines; this cannot be better done than by reading Mr. Alfred Wolff's treatise on "Wind-Mills," a work issued lately by Messrs. John Wiley & Sons, of New York City.

It is not in wind-mills and bridges only that the Japanese would do well to look to America for methods of doing work; for in almost all branches of engineering the existing conditions in the United States are similar to those in Japan. In both countries there is a great deal of work to be done with a decidedly limited amount of capital, rendering absolutely necessary a profound study of true economy. In respect to engineering work Japan stands to-day in the position occupied by America some thirty or forty years ago. Since that time no country in the world can compare with the United States in the amount of progress made; and you will find that the people of that country readily acknowledge that their success has depended primarily upon their engineers.

The problem of where to purchase the various kinds of engineering material abroad is one that you ought to solve by practical investigation. Japan should obtain her supplies from those countries which will furnish them of the required quality at the lowest rate and in the shortest time. To England you should look for ships, steel rails, and rough ironwork, to Germany or England for cannon, and to America for iron bridges and roofs, structural shape iron, in which quality not cheapness is the desideratum, and all kinds of complicated machinery.

The best way to settle this question is to keep posted on the prices of all kinds of engineering material in the various producing countries, obtain as correctly as possible the opinions of disinterested parties concerning the respective qualities of the same, and in doubtful cases purchase samples from each country. Remember that of several articles the one that costs the least is not necessarily the cheapest, but that it is the one which will accomplish its purpose most efficiently for the longest time and with the least expense for repairs and renewals.

And now a few words of advice to those engineers who are just beginning the practice of their profession. You must all feel instinctively that before you lies a great amount of work to be performed, and that the scope for your energies is practically unlimited; nevertheless, I feel sure that there are many of you who are possessed of plenty of ambition, energy, and ability, yet do not know either how to employ your spare time, or to what object to direct your zeal. Such for several years after graduating was my own condition, and I never cease to regret the many hours of valuable time that I wasted simply for want of a little good advice as to the manner in which they might have been properly employed.

Almost all that a young engineer can do immediately after graduating and obtaining a subordinate position on some practical work, is to use every spare hour studying books that he did not have time to read during his course. In order to do so satisfactorily I would suggest that he carry about his person at all times an engineering book of small dimensions, that he can peruse at odd moments. Besides this he should always have on hand one or two works of larger size to read in the evenings or at other times when he has two or three hours to spare. The class of books thus read should be of an eminently practical nature. Indeed, you may make it a rule to look with suspicion upon any engineering treatise that at first sight appears to be composed principally of mathematics. Do not misunderstand me, I do not state that you should condemn any book merely for this reason; if you were to make a practice of so doing, you would occasionally be wrong.

For some time I have been endeavoring to write a paper entitled "Books for Japanese Engineers," but have not yet succeeded. Within six months, however, I hope to send it to this society. Meanwhile let me recommend to you the following: Trautwine's Pocket-Book, Henck's Field Book for Engineers, Burr's Stresses in Bridge and Roof Trusses, Du Bois' Strains in Framed Structures, Simms' Practical Tunnelling, Burr's Elasticity and Resistance of the Materials of Engineering, Wood's Resistance of Materials, Vose's Manual for Railroad Engineers, Gillespie's Roads and Railroads, Haupt's Topographer, Harcourt's Harbors, also his Rivers and Canals, Latham's Sanitary Engineering, Kutter's Hydraulic Formulæ by Jackson, Weisbach's Mechanics of Engineering by Coxe, also Vol. II. of same by Du Bois, and Fanning's Water Supply. In purchasing any one or all of these you can make no mistake. Their prices can be obtained from the principal English and American catalogues of scientific books, such as Spon's, Wiley's and Van Nostrand's, the latest editions of which every engineer ought to possess, especially as they are to be had for the asking.

In respect to purchasing books, Japanese engineers labor under a disadvantage. The demand for technical literature is so small that the booksellers of this country charge high prices for books, and keep no stock on hand. To obtain an engineering book requires at least three, often six, months. Both time and money would be saved, if, as a society, you were to make arrangements with certain English and American booksellers, by which they would forward books immediately to your post-office addresses, notifying you of the cost, including postage, and charging them to the society.

As the young engineer begins to have more experience with the work on which he is engaged, let him try to originate methods of doing things which will be an improvement on the old ones. Let him especially try to *systematize* the methods of doing work: in this line more than in any other good results can be accomplished.

It is well to have a pocket notebook with an index, in which to record anything which may prove of value in the future.

During the first four or five years of one's professional experience it is a mistake to lend one's energies too much to the making of money: it is far better to strive after knowledge and reputation.

It ought to be the ambition of every young engineer to connect himself, as soon as he is qualified, with the principal engineering societies of his own and other countries.

As soon as he feels sure that he has ascertained something original which bids fair to be of practical value, or as soon as he has thoroughly systematized any class of work, it is well for him to write a paper or papers for one or more of the societies of which he is a member. Going into print should be done cautiously, for by writing carelessly prepared papers some engineers have materially injured their professional prospects.

Above all, never get discouraged if your professional advancement be slow: your chance will surely come, possibly when you least expect it, provided that you continue to work faithfully and endeavor in every possible way to fit yourself for a high position in the profession.

There is a very fair collection of engineering works in the library of the Imperial University. Arrangements might be made by which they could be borrowed from it by depositing an amount of money that would cover their value; but it should be optional with the head of the engineering college whether certain books be lent, because they might be necessary for the college course.

There has lately been established in the civil engineering department of the University a cabinet of catalogues and advertising circulars pertaining to engineering work. It is not yet complete, but is making very satisfactory progress. The contents will be grouped according to certain assumed divisions of the subject of engineering, so that one can lay his hand immediately upon what he wants. This cabinet, being entirely independent of the University Library, may be used by any engineer who wishes to consult anything in it.

I have already promised to do my best to obtain positions in America for half a dozen young Japanese engineers, and have no doubt that I shall sooner or later succeed in my endeavor. America is the country to which to go in order to obtain practical knowledge in nearly every branch of engineering. It is so large a country and the requirements there are so great that all kinds of engineering work are going on simultaneously at all times. Moreover, the Americans as a race are a kindly, generous people, and in no class more so than among technical men, hence, in going to their country you may count upon kind treatment. Upon this point I think that every Japanese engineer who has visited America will agree with me. In speaking so highly of the Americans and American engineering, do not imagine that I am praising my own nationality, for I am a Britisher. Please remember that I shall ever be ready and willing to do my best to find a position for any Japanese engineer, provided that I be acquainted with him or that he be well recommended to me by anyone in whom I have confidence. Such positions would not be very remunerative, but they would offer sufficient compensation to pay living expenses. In no other country in the world are ability, energy, and perseverance so quickly and adequately rewarded as in the United States; consequently, those who go there provided with these qualifications are sure to succeed eventually.

Do not imagine that I am advising any of you to go there to settle. It is your duty to your country to return and give to it the benefit of the practical experience acquired abroad. There are plenty of positions for good native engineers in Japan, and there is no training that will command so much confidence as foreign practice.

My work in Japan is fast drawing to a close, and I will leave with many regrets this pleasant country and kindly people. But the greatest regret which I have is that the amount of effective work that I have performed in this country is so limited. It is not my fault, however, for I have made many attempts, most of which were failures. Were it not for the Memoir which I have written for you, I would be ashamed to leave the country after graduating in four years only eight men from my department.

But I feel confident that the effect of the Memoir will be the establishment of a new order of affairs in structural ironwork.

In order that you may judge for yourselves as to the value of the adverse criticisms which that work has met with from some of the English engineers in Japan, I have had printed in pamphlet form everything concerning the Memoir and the resulting topics of discussion that has appeared in the "Japan Mail." A copy will be sent to each of you in a few days. All I ask is that you will read it carefully, then form your opinion as to the relative merits of American and English methods of bridge designing.

And now, gentlemen, as this is the last time that I may meet many of you, I must bid you farewell. My professional associations in Japan have been pleasant, and the treatment accorded me by the Japanese government has been most kind and considerate; consequently, I expect that in future years, amid the activity, responsibility, and anxiety that are inseparable from the life of an engineer practicing in America, I shall often look back with regret to the quiet and easy life that, with few exceptions, is characteristic of government employ in the Land of the Rising Sun.

CIVIL ENGINEERING
EDUCATION.

INTRODUCTORY NOTES.

The paper entitled "Civil Engineering Education" was written late in 1886 and published in Engineering News in January, 1887. Its author had then spent five years in active practice and six years teaching civil engineering, hence was prepared to discuss the subject from the point of view of both the practitioner and the educator.

Upon returning from a term of four years' teaching in the Imperial University of Japan, Dr. Waddell entered active practice, and, as he expected never to teach again, he embodied his ideas of a course in civil engineering and methods of instruction in this exhaustive paper. And it is noteworthy that the advance in civil engineering education which has since taken place has very closely followed the lines indicated. No engineering school has inaugurated a five years' course, but many have increased their requirements materially, and several now offer a graduate course.

The subject has been and always will be of deep interest to engineers; consequently, it is not surprising that the discussions which followed the publication of the paper should be of the highest character.

In planning the ideal course, Dr. Waddell had in view a technical school similar to the Rensselaer Polytechnic Institute, where he received his education and served as an instructor. It was and is his idea that a technical school offering a course of exceptionally high character such as he outlined will yet be established in this country and provided with the means necessary for ample equipment and the employment of a faculty composed of men already eminent in their respective lines; in other words, an ideal school of civil engineering, eminently superior in all respects to the best of our present institutions. In these days of magnificent endowments such a thing is not impossible, however Utopian it may seem. Dr. Waddell has taught almost every technical subject required in a civil engineering course and has a passion for engineering education, hence the editor once inquired whether he would give up his practice to undertake the management of such a school. He replied that he would not unless he had acquired independent means, for, in his opinion, the director of such a school should have but one object in life, the advancement of the institution.

The course of instruction laid down in the paper is, of course, ideal, and few will agree that it is in its entirety the proper course to establish, but it is distinctly in advance of the courses offered by our better institutions. During the last fifteen years, especially since the founding of the Society for the Promotion of Engineering Education, great advances have been made in the requirements for matriculation, the character of the courses offered, the methods of teaching, and the equipment of laboratories, but much remains to be done before the engineering graduate will be so broadly and thoroughly prepared for his professional career as he should be to attain the highest development. The supply of technically trained men is growing more rapidly than pure engineering demands, but large numbers of engineering graduates are being employed in the business and management of manufacturing companies. The half-trained men from the correspondence schools, the minor engineering schools, and the technical high schools of Europe become the "hewers of wood and drawers of water" in the profession. The higher positions must be filled by men of exceptional training, energy, and ability. Hence, it is essential that our better institutions shall provide courses of increasingly high character. The matter is a subject of frequent discussion by engineers and engineering educators, and advancement is very manifest, but breadth is still notably lacking in the engineer's training.

The course outlined by Dr. Waddell, or any similar course, will undoubtedly produce men of high training, but they will be technists purely and will lack the broad, general culture essential to the highest development of the man, and, consequently, to the greatest success as an engineer. The able technist fills a high place, but if he be no more than a technist, he will be unable to reach the plane occupied by the broad, cultured engineer, to control or influence men in their business, social, and other relations. His functions will be limited to design and construction, while the broader engineer adds to these the functions of the organizer, the business man, and the financier. The civil engineer of the present day is materially hampered by the narrow character of his education; and the tendency toward specialization within the field of engineering does not broaden him. It requires no gift of prophecy to see that the day is not very distant when the thoroughly educated engineer, like the best equipped lawyers, doctors, and preachers, must prepare for his professional studies by taking a collegiate course or its equivalent. And in course of time even students so equipped will find it advantageous to pursue graduate professional studies. Lack of funds and the unwillingness to spend so much time in preparation will undoubtedly deter the great majority from studying so broadly, and the larger number of engineering schools will continue to receive students who have not pursued a collegiate course of study. It is for the education of this great majority that the perfect, practical engineering course must be designed.

Not many years since the teaching equipment of a technical school consisted of a moderate library and a laboratory provided with the means for teaching elementary physics and chemistry. In a recent address the president of Sigma Xi Society stated that about twenty-five years since, "while an undergraduate in one of the oldest and most dignified professional colleges in the United States, I found that the only microscope the institution possessed was carefully kept under lock and key, lest perchance it should come into the unskilled hands of the students." From this condition to the present, in which every school of standing has laboratories and shops of no mean proportions and equipped with modern tools and appliances, is indeed a far cry, yet the change has been wrought within a quarter of a century. Who will undertake to say what another twenty-five years will bring forth? The millionaires are giving freely of their substance, and the less wealthy in proportion, for the establishment and development of technical schools, schools often surpassing the dreams of the educator of a few years since in the wealth of their equipment. The student of to-day is enabled to get his practical knowledge at first hand, and to apply from day to day the principles just learned in his theoretical studies, and, consequently, to fix them in his mind beyond danger of loss.

These conditions are inducing rapid changes in the courses of study. The student is directly aroused and he remembers what he sees and does. He is led to make tests and experiments and is thus taught to think rather than to memorize.

The recent enormous industrial development of the world has greatly increased the breadth of the various branches of engineering, civil engineering no less than the others, and instruction in shop practice, in the testing and manufacture of materials, and in the construction and operation of works has increased proportionately; consequently, in the better schools, the time formerly spent upon the practice of the various branches of surveying is now devoted to work in the shops and laboratories, and a portion of the summer vacation is given up to the field work. These developments were not fully in view when Dr. Waddell mapped out his ideal course, hence it is not closely in accord with them, but in most other respects the advancement of the past eighteen years has been largely along the lines laid down in his paper. Indeed, it is not improbable that the paper and the valuable discussions to which it gave rise have contributed greatly to the recent advancement in engineering education.

CIVIL ENGINEERING EDUCATION.

The subject of the proper education for civil engineers, important as it is, has never yet been systematically and adequately treated. Numerous papers, some of them of undoubted value, have appeared of late years in the technical periodicals of America, and quite lately the subject has been taken up in England; but none of the authors of these papers has attempted to cover the whole ground or go at all into detail. For the last six years the author has been endeavoring to prepare a comparatively complete paper upon the subject, but has repeatedly failed, each time coming to the conclusion that his experience has not been sufficiently extended, and finally deciding that an entire lifetime devoted to the teaching and practice of engineering would not be enough to qualify one as an authority upon how all branches of the profession should be taught and learned.

As the field of civil engineering has, within the last half century, become greatly extended, it results that, if any one wish to rise to eminence in the profession, he has now to choose a specialty and confine himself to it. Even such a one at the end of a long lifetime will probably have to confess that he cannot consider himself thoroughly posted concerning everything connected with his specialty, and that there is and always will be a great deal to be learned.

As civil engineering is composed of specialties, it is evident that to be able to say exactly how any branch of the subject should be taught one should not only be a specialist in that branch, but also should have had some experience in teaching. Hence the conclusion is inevitable that, to do justice to the subject, it must be treated and discussed by a number of engineers and professors of engineering. With this object in view the author has prepared this paper, trusting that it may receive proper discussion.

Although most of the branches of civil engineering are here dealt with, the writer wishes it to be distinctly understood that he has no intention to try to cover the entire ground even in one branch; and that, even if his opinions appear to be emphatically asserted, they are so far from being set that he hopes they may be considerably modified by the resulting discussions.

Anyone who has given the matter any attention whatsoever must have come to the decision that the methods of instruction in technical schools have not kept pace with the great strides made of late years in engineering practice, and anyone who has not heretofore given the subject special attention would be quickly convinced that such is the case, if he were to compare the curricula of the principal institutions where engineering is taught, as given in the catalogues of ten years ago, with those contained in the catalogues last issued. Moreover, he would be confirmed in his conclusions if he were to spend a few weeks in examining some of these institutions, noting how the old methods of teaching are religiously adhered to and what antiquated text-books are still employed. He would be impressed by the fact that what progress has been made is to be found not in the old schools of established reputation, but in the newer ones and even in some of those which do not make a specialty of engineering, or even of science, and which employ only one professor of civil engineering. In many of the latter, though, he would probably observe that decided progress has been made in only one department of the subject, the other departments being at a standstill or retrograding.

Such being the state of affairs, the question arises, "What are the causes?"

They are both numerous and varied. Among them are the following: a lack of money for the purchase of apparatus and for the adequate payment of instructors; bad directorship and the management of the institution upon narrow and short-sighted principles; the fossilization of professors, who, finding that after a year or two the routine of teaching is not very onerous, are content to take life easily and thus fall behind the times; the employment of incompetent and inexperienced instructors, partially from motives of economy and partially because of the common but mistaken idea that it takes more ability to practice engineering than to teach it; allowing or forcing a professor to teach too many and too different branches; a scarcity of proper text-books; the neglect of the study of the *science of technical teaching*; the hampering of the faculty by trustees who are not engineers, and who are consequently entirely ignorant of what is requisite for the success of the course; the want of a good, ample, and well-kept library; the absence of harmony in the governing faculty; low standard for admission, so placed as to obtain a large number of students either to make the institution pay or to make it appear to be in a flourishing condition; the lowering of the graduation standard for the same purposes; the absence of a proper harmonizing of theory and practice, in some institutions the former being considered the great requisite, and in others the latter; the enforced spending of students' time in a useless manner; the introduction into the curriculum of subjects that are either not needed at all or that the students should be prepared upon before being allowed to enter the institution, and the entire neglect of subjects of the greatest importance; the omission of designing from the curriculum; the short time allowed for completing the course; the want of harmony between professors and students; and faulty and inadequate methods of examination.

Of all these reasons the most serious is undoubtedly the want of money, for it entails many of the others. To ensure success the income of any institution should be sufficient to pay all salaries, purchase apparatus and supplies, and meet all running expenses without relying at all upon students' fees.

After a sufficiency of money, the next most important requirement for the success of an institution is good management. The real governing power may lie in the hands of a president, a director, or the faculty as a body, or may be divided between any two or even all three, although in most cases when the latter arrangement is supposed to hold, an investigation will show that the power of one or more of these parties is merely nominal.

Probably the best arrangement that could be made would be to entrust the business management of the institution to the director, making him responsible to the board of trustees, and to leave all matters relating to the curriculum to the faculty; by the latter term meaning the director, professors, and assistant professors. The method of investing the director with autocratic power is liable to work very badly; moreover, it is incompatible with American principles.

It is no easy matter to find a man in every way suitable for a director, and who would be willing to accept the position. Among the principal requisites are tact, energy, integrity, ability, and experience. His career, both professional and other, should be without flaw, and his bearing should be such as to command the confidence and respect of the faculty, the students, and the general public.

He should not be required to teach, but should be capable of so doing in several of the departments; indeed, it would not be a bad plan for him to take a class occasionally (of course with the consent of the professor) in order to judge of the progress which the students are making. That such men as the one described are to be found in the engineering profession, nobody is likely to deny; the difficulty would be to offer them sufficient inducements to forsake remunerative practice.

The next essential is the employment of thoroughly competent instructors. There should be no difficulty found in this matter if the salaries offered be large enough. A professor of the proper kind is not liable to fossilization, hence when symptoms of the disease begin to appear, the most effectual remedy to apply is a change of climate: it will be found to work well both for the professor and for the institution. Incompetent instructors and those who have lost their energy should not be retained from mistaken motives of sympathy, but in the case of a professor who has worked long and faithfully for the institution and who, from declining health, has lost the vigor necessary to give a thorough course of instruction, an ample pension should be voted him and he should be permanently retired.

If a professor has too many classes to attend to and too many subjects of widely varying character to occupy his mind, he is liable to degenerate into a mere teaching machine; on the other hand, if he has too little work allotted him, he is apt to become lazy and shirk his duties. If circumstances be favorable, it is well to have a large number of professors who are specialists in various branches, and to require them to work only a certain fixed time in each year. The salary of each one should be large enough to pay him more for the time spent in teaching than he would be apt to earn in the same time in practice. In this way there would be no inducement to neglect the course for the sake of outside work. It would be better, though, to require certain members of the faculty to devote their entire energies to the institution.

If circumstances be unfavorable for the above-described arrangement, the next best thing is to supplement the instruction in the various practical branches by lectures given by specialists.

If a state of harmony exists between the different members of the faculty, the methods of instruction can be greatly improved by friendly discussion at faculty meetings.

A complete library of the best and latest technical works is absolutely essential to a first-class technical school. The number of copies of each book in the library should be adjusted to the wants of the students; and it would not be a bad plan to arrange for students who are obtaining their education in spite of straightened circumstances, to have the use of text-books belonging to the library. An arrangement should be made with certain booksellers by which a single copy of each new scientific or technical work would be sent to the library as soon as issued; and monthly notices of the receipt of such books should be distributed among the professors in order to determine the expediency of purchasing more copies or adopting the said works as text-books.

A large, attractive, well-stocked, and well-kept reading room should be the adjunct of such a library. In it should be found all the scientific and technical periodicals in the English, French, and German languages, and the number of copies of each periodical should be adjusted to the number and requirements of the readers. Earnest students would freely patronize such a reading room and would be benefited greatly thereby. Strict maintenance of order would be an essential element for its success.

The omission of designing from the curriculum of a technical course is one of the gravest errors that can be made. A single design in the whole course is not enough; there should be one in each of the courses in which it is practicable to have one. They should be made under the direct supervision of a thoroughly practical and competent instructor, and should be completed in the rooms of the institution. No design should be considered complete without a full, detailed estimate of cost, figured according to current prices. Most students, and possibly some professors, are apt to think that engineering and business are two entirely distinct affairs; it is only when they go out into practice that they will find what a grave mistake they have made. In designing, special stress should be laid upon the consideration of economy, for it is this particular which is characteristic of the American engineer, and which gives him the advantage when coming into competition with his European brethren.

That the line between theory and practice can never be accurately drawn should be borne in mind by both instructors and students. A man well posted in theory but not in practice may be an excellent mathematician, but he is not an engineer; while, on the other hand, no man can be truly posted in practice who does not understand enough mathematics to establish or understand the establishment of most of the equations which he uses in his calculations. Those who have a penchant for long and complicated formulæ, rule-of-thumb men, and pocket-book engineers are seldom, if ever, capable of doing first-class engineering work, unless it be of a low order.

Ten years ago the want of proper text-books was a serious impediment to both professors and students of engineering. To-day matters in this respect are somewhat improved, but sufficient first-class, properly written, practical, text-books are still a desideratum. For the higher classes in an engineering course, books written especially for students are unnecessary, if not really objectionable. Such students should use books written for engineers; and if there be more than one good book on any particular subject, they should not confine themselves to one author, for by reading the works of many men one's views become broader, and one's knowledge more extended. Concerning this subject of engineering literature it is not necessary to say more here, for the author has lately written on it in two papers published by engineering societies.

The time allowed for completing most technical courses is too short, and the most practical and useful courses are generally left till the last year. With much higher and more extended entrance requirements than are usual in technical schools, four years might be found sufficient for giving a pretty thorough course in civil engineering; but, in the opinion of the author, five years would be much better. It is not well to require, for entrance, preparation on very many important subjects; because students would be admitted who were not thoroughly grounded in the elementary studies. For instance, it would not be well to require analytic geometry and the calculus at the entrance examination, for these are seldom, if ever, properly taught outside of technical schools—nor (it is a pity to have to confess it) always thoroughly within them.

The more preparatory schools there are for technical institutions the better for technical education; and in case the faculty of an engineering course have perfect confidence in the instructors of a preparatory school, it is well to permit graduates of the latter to enter the former without passing an examination. Such a course of action would encourage young men to prepare themselves thoroughly in preliminary studies before entering technical schools.

A want of harmony between professors and students is one of the greatest drawbacks to the success of any educational institution. Students should look upon their professors as their best friends, who are doing their utmost to prepare the young men entrusted to their charge for their coming life struggle. Although a high standard of scholarship in all departments is absolutely necessary to the success of any educational institution, this should cause no ill-feeling between students and professors. The former should recognize the fact that if any one of their number cannot come up to the standard, he should be dropped, and that there is no other course open to the faculty.

Students who have failed to pass the examinations should not be allowed more than one chance to regain their lost position; such an arrangement tends to make students work regularly and systematically. In fact, it might be better to allow no one a second examination, except in case of sickness. Conditioned students will always come under one of the following groups: first, those who are lacking in ability; second, those who, from sickness or some similar cause, have been prevented from attending to their classes and their work; and third, those who are wanting, not in ability but in application. Sympathy on the part of the examiners for those of the first group is a great mistake. Those of the second group ought certainly to be allowed another chance; and a high standard with rigid rules will reduce the number in the third group to a minimum. Men of good ability but of chronic laziness are, as far as the welfare of the class is concerned, much better dropped than retained.

Much of the success or failure of a technical institution depends upon its methods of holding examinations. Of these there are many varieties in different institutions, and nearly all are faulty. The English method, which passes or rejects a student almost solely on the result of his examination, is bad for two reasons; first, it encourages cramming and the employment of tutors who have no direct connection with the institution, thereby making the true value of a student's knowledge more apparent than real; second, it places a man of a nervous temperament at a great disadvantage. Cases of students who have proved during the course that they are well posted on the subject failing from nervousness at examination are by no means uncommon. It is obviously unjust to make a man's passing in such a case depend wholly upon his examination. On the other hand, the method employed at certain American institutions is equally faulty. There the students are told a week beforehand what will be the blackboard topics for examination, and are certain that during the oral examinations they will be asked no questions that have not been asked during the interrogations of the advance and review courses. This method for students in the highest branches of learning is a mere farce.

Some instructors prefer written and others oral examinations; but in the author's opinion, unless there be peculiar conditions which are not liable to occur in America, both methods should nearly always be employed. Written examinations are better where the work is principally mathematical; but there is no way to test a man's practical knowledge of a technical subject that can compare with the oral examination. But there is more than one way of holding an oral examination. That of asking each student a few questions from the course, as given during advance and review, in the presence of a number of his classmates, is entirely inadequate. Each student should be interrogated privately in the presence of at least two examiners for from half an hour to an hour and a half, the time depending upon the manner in which he answers the questions.

The time at which examinations are to be held is an important consideration. The method of requiring a candidate for graduation to pass at the end of a four years' course a number of examinations upon all that he has studied during the four years is too hard upon the student, and tends to make his knowledge merely superficial. Half-yearly examinations are much better. The method of letting a student come up to examination whenever he feels prepared tends to upset the system of an institution, and causes the examiners unnecessary labor.

Written examinations should last four or five hours, and the number of questions to be answered in that time should be adjusted to the capacity of slow students, for it is not always the most rapid thinkers who achieve the greatest professional success.

In preparing examination papers on technical subjects such questions should be chosen as will indicate the practical and useful knowledge of the students, and not those which involve mathematical demonstrations, merely for the sake of the mathematics.

The question as to what should and what should not be taught in a course of civil engineering is one upon which there is a great variety of opinions. Some engineers say, "teach the student merely the elements of engineering and ground him well in mathematics, so that after graduating he can choose a specialty and devote himself to it." Others say "give him a good mathematical education and let him pick up practical methods afterwards; there are plenty of chances to get a good practical education at any time of life, but mathematics should be learned when young." Others, on the contrary, say "what is the use of filling students' minds with a lot of mathematical rubbish that they will forget just as soon as they go into practice? Give them a good, practical education and don't waste their time." These views are extreme, and therefore to be avoided. It is true, as before stated, that nowadays, when the field of civil engineering has become so large, it is necessary to success that one devote himself specially to one or two branches of the profession; but this is no reason why he should be practically ignorant of all the other branches.

The writer's method would be to instruct the student both theoretically and practically in every branch of the profession as much as possible, so that when he adopts a specialty he will know something about other branches and be able to form an intelligent opinion about the works of others. Besides, in some departments of engineering, an engineer requires to be well posted in many branches of the profession; for instance, a city engineer has to be well informed in road-making, sewerage, water supply, surveying, architecture (at least elementarily), and earthwork, besides being also a good business man.

In the writer's opinion the course of instruction in pure mathematics for civil engineers should end with the calculus and least squares. One seldom, if ever, finds use for quaternions, elliptic functions, transcendentals, etc.; these should be left for professed mathematicians. But unless one has been thoroughly and intelligently drilled in arithmetic, algebra, geometry, trigonometry, analytic geometry, differential and integral calculus, and least squares, he will sooner or later in his practice have cause to regret that his education in these studies was neglected.

The proper way to correct existing evils and deficiencies in American engineering courses is not to reduce the amount of theory, but to increase the amount of practice, and throw many of the elementary subjects taught into the entrance examination. By the term "practice" is not meant, as is usually the case, merely surveying; but surveying, designing, estimating, and shopwork.

Purely technical courses should be made no more mathematical than necessary, and all mathematics should be made as simple as possible. The old idea that the more one has to puzzle over intentionally knotty mathematical points the more will his mind be developed is a fallacy. There are plenty of useful, practical studies in these days that will give to one's mind all the development that can be desired. For the same reason if there be typographical errors or other mistakes in a book, they should be pointed out to a student before he uses it; for it is a mistaken idea that in discovering the errors he gains knowledge—on the contrary, he simply loses temper. There is nothing more exasperating than to work an hour or more trying to solve an equation, and finally ascertain that the book is wrong.

Students should not at the same time have on hand more than three or four courses. Too many studies confuse the mind and discourage a student; while a continued application to one subject is wearisome; hence it is well to have one or two more to afford a little variety.

The general idea that, if possible, each course should be given out of but one text-book is wrong and is based upon nothing but a false economy. By confining one's reading on any subject to a single author one often sees only one side of the question, and it is seldom that a single book can cover the whole ground properly. On the other hand, there are often portions of different books that are nearly identical; in such cases the instructor should see that the student does not waste time in going over the same ground twice; sometimes, however, by so doing he gains by impressing the matter upon his mind.

No doubt there is such a thing as "the art of studying," and anyone who has mastered it can do much more work in a given time and do it better than one who has not. This is not a case of the development of the faculty of memory, though that, too, when the faculty be not misapplied, is advantageous. By much practice, an exercise of the will, and a systematizing of methods, one can so train his mind as to grasp readily mathematical reasoning, see at a glance mathematical deductions, and perform readily other difficult mental feats. In this respect the Japanese far excel Europeans and Americans. The amount of work that a Japanese science student gets through in a day would appall most of the men in American universities. Moreover, they do it just as thoroughly as their American brethren, and without spending upon it any more time.

If a student of the higher classes in a technical school work faithfully from 8 a. m. till noon and from one o'clock till half-past three or four, also an hour in the evening, he ought to accomplish sufficient for one day, but under-classmen would require to work an hour or two more in the evening. There are two reasons for this; first, the under-classmen have more mathematics; and second, they have not had so much mental discipline as the upper-classmen. Much study at night is not good for the student's health; hence for this reason, if for no other, they should be made to work during the day in the buildings of the institution. Students should be encouraged, but not compelled, to read outside of working hours at least a few books not connected with the course; such works, for example, as those of Darwin, Huxley, Spencer, and Tyndall and the periodicals "Nature" and the "Popular Science Monthly." A little light literature occasionally will do no harm, for it will serve to give the mind a rest.

The practice of having no classes on Saturdays is not conducive to the accomplishment of a large amount of work. It ought to be a sufficient concession to popular notions to stop work on Saturdays at noon.

The vacations and holidays should be so arranged as to have nine solid working months in the year; this would give two hundred and fifteen days, which, at seven and a half hours per day, would make over sixteen hundred hours per year, to be passed either in the buildings of the institution or in the field.

There are two methods of instruction in general use in technical schools, viz., the lecture system and the recitation system; to these the writer would add a third and call it the consultation system.

The lecture system, although employed almost exclusively in England and Germany, and to a great extent in the United States, is in the author's opinion by no means a good method of imparting instruction to science students. In the first place, the ground which a lecturer can cover in a day is about one-third or one-fourth as great as a good student can cover in the same time by using text-books. In the second place, one can in general remember much better what he has learned from a book than what he has heard at a lecture, because, by the former method he can go slowly over the difficult parts and rapidly over the simple ones, while by the latter he is compelled to think just as fast as the lecturer talks and no faster. In the third place, lecture notes, besides being an imposition on the students, are a delusion and a snare, for they are very seldom correctly taken even when copied from the blackboard. Is it not much better and more economical of both the professor's and the students' time to have the notes printed in book or pamphlet form? In such cases the excuse is sometimes made that the professor has an objection to appearing in print, or that by publishing the notes he would be giving away the secrets of the trade. In engineering there should be no such thing as a "secret of the trade"; every true engineer is always ready and glad to let others benefit by his experience; and anyone who fears to put his teachings into print is not fit to be a professor. There are but three cases in which lectures, other than experimental ones, may be advantageously given; first, one at the opening of a course; second, another at the end of the same; and third, when the information to be given cannot be found in any text-book.

The recitation system is much more satisfactory than the lecture system; but it, too, has its disadvantages. It is undoubtedly very thorough and, consequently, well adapted for the lower classes, the students of which are not as yet well broken into proper methods of study, but for upper-classmen it savors too much of the boys' school. Moreover, it tends to make students strive for appearance rather than reality, and encourages them to be dishonest. Another disadvantage is that it tends to prevent students from asking the instructor questions connected with their work: for they fear that by their so doing he will acquire a poor opinion of their capabilities, and will give them low marks in consequence. But the recitation system in spite of its disadvantages is by far the best for the courses in pure mathematics and rational mechanics. When students are unwilling to work, it can also be used advantageously in technical mechanics.

Before proceeding to discuss the third, or consultation system, it will be well to define what is meant thereby. It consists essentially in laying out for the class a certain course of reading in any subject, dividing it, if thought advisable, into daily lessons, and each day at a certain time answering any questions on it that the students may ask. This method often reverts naturally to the lecture system, since one question leads to another, and the professor, if properly interested in the subject, is very apt to digress and thus give the students many points that are not to be found in the text-books.

Such informal lectures are far superior to those ordinarily given, for they deal only with the difficult points, and tend to show the practical application of what otherwise might appear to the students mere theory. The amount of ground that can be covered by this system is nearly double that which can be covered by the recitation system, provided that the students are all working for the sake of obtaining knowledge and not for diplomas merely. The success of the consultation system is entirely dependent upon the good faith and earnestness of purpose of the students and the practical competency of the instructor. If the latter be thoroughly posted in all the subjects he teaches, he will be able to answer readily any questions propounded by the students, and the amount of labor involved in teaching is much less by this method than by either of the others. On the contrary, if the instructor be not thoroughly posted on both the theory and practice of his subjects, the consultation system will involve for him a great deal of labor, and he will constantly be asked questions that he cannot answer.

With fairly good students the consultation system can be advantageously used in combination with the recitation system; but when the students are not of a high grade, and are endeavoring to study just enough to graduate and no more, it should not be attempted, unless the faculty be willing to drop a large portion of the class.

The author has tried the consultation system for over three years in teaching Japanese students, and the excellence of their extended and difficult examinations gives ample proof of its thoroughness and efficiency for the higher classes. For the lower classes its advantages were not so marked; consequently in these the method was combined with the recitation system and occasional lectures.

Students should be taught to work together, both while studying and designing, without interfering with each other. If the class be large, it should be divided into sections, each section having a room by itself. By walking around among the students occasionally the instructor can aid them materially in their studies and designs by answering questions, pointing out faults, and suggesting improvements; but in so doing he should be careful not to do too much thinking for indolent men. On this account, it is often advisable not to answer a student's question, but to tell him to study out the point for himself.

One important conclusion that the author has drawn from experience, both as a student and as an instructor, is that really to appreciate a lecture, the hearer must be fairly well informed on the subject treated. Otherwise so many new facts and ideas will be presented to his mind that he will be unable to grasp them, and, if he attempt to make notes during the course of the lecture, he will fail to understand a large portion of the discourse. Hence, if lectures on technical subjects be given to the classes by eminent engineers, it should be after the regular courses in these subjects are finished.

The method of supplementing practical courses by visiting engineering works, either finished or in course of construction, is of great advantage if properly employed; but such excursions are too often a farce and a mere excuse for the students to have a good time. The best time to visit any piece of engineering is just after the class has finished studying the course which treats of such work, and just before commencing their designs. To make the visit really useful, the engineer of the work should be induced to accompany the class and explain everything connected with it in a systematic and detailed manner. If possible, he should show them the original plans according to which the works were built, and explain the order in which the different parts were begun and finished. He should give them also, if possible, the cost of the different parts of the work, both estimated and actual. A visit to work in course of construction is generally preferable to inspecting that which is finished.

Students should be advised to spend a portion of their summer vacations in inspecting engineering works; and it is much better to visit those works that are connected with finished studies than to try to get a practical idea of subjects before the courses on them are begun. Students should consult with their instructors before the vacation begins regarding the places it is advisable to visit, and should obtain from them, if necessary, letters of introduction to the managers or engineers of such works.

Concerning the benefits to be derived from reviewing courses before examination there may be two opinions. Certainly it affords a more thorough drill, and in this way forces the poorer students on; but it is a question whether the time thus occupied could not often be spent to greater advantage. Adopting or dispensing with the review courses might be left to the judgment of the instructor, and if he find that the class understands the subject at the end of the advance course, he could omit the review. For the elementary courses, particularly those in pure mathematics and analytical mechanics, reviews are undoubtedly beneficial, because it is in these courses especially that students require thorough drill.

And now a few words regarding the qualifications and duties of a professor of civil engineering and his methods of management. First as to his qualifications—he should have had a thorough course of study and be a graduate of one of the leading technical schools, besides having had several years' experience in the actual practice of his profession. He should have made a special study of some particular branch of engineering and have obtained a reputation as an expert in it. He should have the capacity for readily imparting his knowledge to others, and be possessed of a certain amount of tact. His reputation, both as a man and an engineer, should be above reproach, in order that he may command the confidence and esteem of those he teaches.

A professor should endeavor to make all his courses as attractive as possible, and to instill into the minds of his students a real taste for work, encouraging them to mental effort by occasional references to the lives of eminent engineers. He should show the practical application of everything he teaches, and avoid the use of all mathematics that are not in harmony with good practice.

He should impress upon the minds of his students that everything which is worth doing at all is worth doing well; and that, if they ever go into contracting, it will, to say the least, be the best policy to do all their work in a thorough and workmanlike manner, even if by so doing their apparent profits be lost.

A professor of a technical course should teach his students that it is not sufficient to make a design that shall be adequately strong and fulfill all the requirements, but that it must also be made in the most economical manner. He should distinguish between true and false economy, and prove that in many cases it is not the most elaborate design that is best for the purpose, and that simplicity is generally an accompaniment of economy. He should endeavor to gain the confidence and good will of his students in every legitimate manner, but not by allowing them to have their own way when that way is not the right one.

A professor should study the mental peculiarities of his students, and, if possible, vary his methods of teaching accordingly.

If an instructor teach a number of different subjects, he should not compel his classes to pay undue attention to the particular branch in which he is most interested, to the neglect of other subjects; nor is it fair to the students to use their time in assisting the instructor to make original investigations. However, such a course of action is not objectionable in teaching post-graduates, provided that their chosen specialty be the same as that of the instructor.

Students should be encouraged to read the technical literature of the day; and it should be considered the duty of each professor to call the attention of his classes to anything in his line of work which appears in the journals, and which in his opinion the students ought to know.

If a professor have spare time from his classes (as should always be the case) he should make some practical use of it, by original investigation, by compilation of the results of the investigations and experience of others, or by attending to a regular engineering practice of some kind. A professor should neglect no opportunity to increase his professional knowledge, and thus render his services as an instructor more valuable. It is well for him to spend at least a portion of each summer vacation in practical work connected with the courses which he teaches. He should not feel at all satisfied with his knowledge of any of his branches, unless he can confidently answer readily any legitimate question thereon propounded by a student; even then he cannot consider himself up to the times unless he reads everything of value as soon as it is published. He should at least glance over each new book connected with his work as soon as it is issued; then, if it prove to be good, he should read it carefully so as to give the benefit of its contents to his students, either by compelling them to read it, or, in exceptional cases, by preparing lectures from it.

It is almost essential for a professor of engineering to join the principal engineering societies of the country and to become acquainted with the leading engineers. Finally, he should be posted in respect to the prices of all kinds of materials, machinery, finished structures, and labor related in any way to his courses, and he should know where the different materials may be purchased to best advantage.

Next, as to the education preliminary to a course of civil engineering, it may be stated, without fear of contradiction, that the broader and more thorough this is the better. Although Latin and Greek are almost useless to the engineer, an acquaintance with one or two modern languages is a great advantage, hardly sufficient, though, to make it advisable to introduce their study into the curriculum of an engineering school. If one could learn them there at all thoroughly, it would be very well to incorporate them in the course; but the fact is that the amount of knowledge so gained is not enough to warrant their study. It is often said that the engineer who cannot read French and German is at a great disadvantage, but the writer wishes to take exception to this statement, for nowadays any work of real value in either of these languages is very soon translated into English. Moreover, many of the engineering treatises in French and German are of a purely mathematical character, and are not to be compared in value to the corresponding modern works published in England and America.

The requirements for entrance into a course of civil engineering will undoubtedly vary with the character and duration of the course, the finances of the institution, and other considerations. In any case the entrance examination should include the following subjects, and a thorough knowledge of them should be insisted upon by the examiners:

- *English.*
  - Spelling.
  - Grammar.
  - Composition.
- *Mathematics.*
  - Arithmetic.
  - Algebra.
  - Geometry.
- Geography.
- Bookkeeping.
- Elementary Physics.
- Elementary Draughting.

The reason why bookkeeping is inserted in the list is because a knowledge of it is necessary to a contracting engineer, and it would be out of place in the curriculum.

The best age for entering a technical school is probably eighteen, though the minimum age might be advantageously fixed at seventeen. It is a disadvantage to enter late in life, unless one has previously been accustomed to hard study.

The following is an ideal course in civil engineering, which can be given only under the most favorable circumstances. To it all others may approach by an asymptotic curve.

For entrance, in addition to the list previously given, the following subjects are to be included:

- Plane and Spherical Trigonometry.
- Projection Drawing.
- Elementary Perspective.
- *Physics.*
  - Heat.
  - Light.
  - Sound.
  - Advanced courses.
- Inorganic Chemistry (Theory).
- Free Hand Drawing.
- *English.*
  - Rhetoric.
  - Criticism.

First Year Subjects.

- *Surveying.*
  - Chain Surveying.
  - Compass Surveying.
  - Transit Surveying.
  - Direct Levelling.
  - Indirect Levelling.
  - Contour Surveying.
  - Stadia Surveying.

- *Mathematics.*
  - Analytic Geometry.
  - Differential and Integral Calculus.
- *Natural Sciences.*
  - Descriptive Astronomy.
  - Mineralogy.
  - Lithology.
  - Technical Geology.
  - Physical Geography.
- *Drawing.*
  - Pen Topography.
  - Colored Topography.
  - Free Hand Drawing.
  - Descriptive Geometry (Plates).
  - Maps for Various Surveys.
- *Road Making.*
  - Common Roads and Streets.
  - Tramways.
- Descriptive Geometry (Theory).
- Shade and Shadows (Elementary).
- Carpentry.

SECOND YEAR SUBJECTS.

- *Surveying.*
  - Omnimeter Surveying.
  - Sextant Surveying.
  - Hydrographical Surveying.
  - Railroad Surveying.
  - Canal Surveying.
  - Sewerage Surveying.
  - Practical Astronomy.
- *Mathematics.*
  - Least Squares.
  - Astronomy.
- *Machinery.*
  - Elements of Mechanism.
  - Machine Construction.
- *Drawing.*
  - Machine Construction (Plates).
  - Maps of Various Surveys.
- *Materials.*
  - Properties of Materials.
  - Resistance of Materials (Math.).
- Rational Mechanics.
- Railroading.
- Sanitary Engineering.
- Shopwork.

THIRD YEAR SUBJECTS.

- *Surveying.*
  - Geodetic Surveying.
  - Mining Surveying.
- *Drawing.*
  - Theses.
  - Maps of Surveys.
  - Pattern Making.
- *Machinery.*
  - Machinery, Tools, etc., used on Engineering Work.
  - Pumps.
- *Natural Sciences.*
  - Electricity (Theory and Experiments).
  - Magnetism (Theory and Experiments).
  - Practical Chemistry.
- *Mechanics.*
  - Thermodynamics.
  - Electrodynamics.
- *Materials.*
  - Metallurgy.
  - Manufacture of Shape Iron and Steel.
  - Foundry Work and Pattern Making.
  - Limes, Cements, and Mortars.
  - Masonry and Brickwork.

- *Earthwork.*
  - Removal of Earth.
  - Tunneling and Rock Excavation.
  - Well Boring.
- *Sub-aqueous Engineering.*
  - Tunneling.
  - Dredging.
- Timber Structures.
- Mining Engineering.
- Mechanical Engineering.
- Electric Engineering.
- Shopwork.
- Writing of Technical Papers.

Fourth Year Subjects.

- *Surveying.*
  - Bridge Survey.
- *Drawing.*
  - Stone Cutting (Plates).
  - Theses.
- *Machinery.*
  - Steam Engine.
  - Hydraulic Motors.
  - Wind Motors.
- *Structures.*
  - Bridges.
  - Roofs.
  - Braced Piers.
- Stone Cutting.
- Theory of Hydraulics.
- Foundations.
- Architecture.
- Shopwork.
- Writing of Technical Papers.

Fifth Year Subjects.

- *Surveying.*
  - Water Works.
- *Drawing.*
  - Theses.
  - Plans.
  - Maps.
- *Structures.*
  - Arches.
  - Retaining Walls.
- *Hydraulics.*
  - Water Supply.
  - River Engineering.
  - Canal Engineering.
- *Marine Engineering.*
  - Harbors.
  - Lighthouses.
  - Buoys.
- Shipbuilding.
- Railroad Management.
- Law of Contracts.
- Engineering Estimates.
- Management of Forces of Men.
- Shopwork.
- Technical Writing.

The following time schedule is merely an approximation, and would have in any actual case to be changed to suit the circumstances. It is given simply to show that the courses laid out can be completed in the time allowed, and the relative amount of time to be devoted to each course. The total number of hours required is in each year less than the available sixteen hundred. The remaining hours can be employed in holding examinations, visiting engineering works, etc. Under the heading "Drawing" is not included the time necessary for making designs, but only that for making plans, maps, and plates. The time allotted for designing will be found in the "Practice" column for each subject.

In the column headed "Preparation" no night work is included, but in the second year under the heading "Practice" is included an allowance for time to be spent at night in making astronomical observations.

The hours under the combined headings "Preparation" and "Recitations or Lectures" can be used as desired under the "consultation system."

TIME SCHEDULE.

FIRST YEAR.

	Hours Required.			
Subject.	*Preparation.*	*Recitations or Lectures.*	*Practice.*	*Total.*
Surveying	150	50	220	420
Mathematics	320	80	...	400
Natural Sciences	120	40	...	160
Drawing	...	...	150	150
Roads, etc.	45	15	...	60
Descriptive Geometry, etc.	60	20	...	80
Carpentry	30	10	...	40
Totals	725	215	370	1310

SECOND YEAR.

	Hours Required.			
Subject.	*Preparation.*	*Recitations or Lectures.*	*Practice.*	*Total.*
Surveying	60	20	320	400
Mathematics	80	20	...	100
Drawing	...	...	150	150
Machinery	60	20	...	80
Materials	75	25	...	100
Mechanics	300	75	...	375
Railroading	60	20	...	80
Sanitary Engineering	60	15	...	75
Shopwork	...	...	100	100
Totals	695	195	570	1460

Third Year.

Subject.	Hours Required.			
	Preparation.	Recitations or Lectures.	Practice.	Total.
Surveying	100	25	160	285
Drawing	...	...	120	120
Machinery	24	8	...	32
Natural Sciences	60	20	250	330
Materials	90	30	...	120
Earthwork	64	16	...	80
Sub-aqueous Engineering	24	6	...	30
Structures	9	3	...	12
Mining Engineering	75	25	...	100
Mechanical Engineering	75	25	...	100
Electric Engineering	75	25	...	100
Shopwork	...	...	100	100
Totals	596	183	630	1409

Fourth Year.

Subject.	Hours Required.			
	Preparation.	Recitations or Lectures.	Practice.	Total.
Surveying	...	...	60	60
Drawing	...	...	60	60
Machinery	200	50	250	500
Structures	160	40	200	400
Stone Cutting	24	6	...	30
Hydraulics	60	15	20	95
Foundations	40	10	60	110
Architecture	45	15	...	60
Shopwork	...	...	100	100
Totals	529	136	750	1415

Fifth Year.

Subject.	Hours Required.			
	Preparation.	Recitations or Lectures.	Practice.	Total.
Surveying	...	...	60	60
Drawing	...	...	40	40
Structures	48	12	50	110
Hydraulics	75	25	150	250
Marine Engineering	90	30	150	270
Shipbuilding	160	40	200	400
Railroad Management	20	10	...	30
Contracts	15	15	...	30
Estimates	...	10	40	50
Management of Forces	14	6	...	20
Shopwork	...	...	100	100
Totals	422	148	790	1360

The smallest staff of professors required for the foregoing ideal course, in the author's opinion, would be the following:

Professor of Geodesy and Surveying.
Professor of Mathematics and Astronomy.
Professor of Mining Engineering, Chemistry, etc.
Professor of Drawing.
Professor of Roads, etc.
Professor of Mechanical Engineering.
Professor of Structures and Materials.
Professor of Electrical Engineering.
Professor of Hydraulics and Sanitary Engineering.
Professor of Architecture.
Professor of Shipbuilding.
Lecturer on Law of Contracts and Technical Writing.

Whenever this class is very large or the work demands it, a professor should be furnished with an assistant; and in the workshops there should be enough skilled mechanics employed to obviate the necessity of relying on the students for the accomplishment of necessary work. Students' time should not be used in the making of models, for the amount of their time to be spent on any one kind of work should be just enough to teach them how to do it; any more than this is wasted.

The qualifications for an assistant are that he be a graduate of a technical school, that he have had at least two or three years' practice in work of the same kind as that with which the courses of the department are concerned, and that he be energetic, desirous of increasing his knowledge, and interested in the class of work which he is required to perform.

The professor of "Geodesy and Surveying" should take all the surveying courses of the first year: omnimeter, sextant, hydrographical and canal surveying in the second year; and geodesy in the third year. He should give instruction in both the theory and the practice in these subjects. The professor of "Mathematics and Astronomy" should take the courses in analytic geometry, calculus, rational mechanics, descriptive astronomy, and practical astronomy. The professor of "Mining Engineering" should take the courses in mineralogy, lithology, technical geology, physical geography, practical chemistry (including blow-pipe analysis), in addition to mining engineering and surveying. The professor of "Drawing" should take all the drawing of the first year and the courses in descriptive geometry (including shades and shadows) and stone cutting. He might also be associated with the professor of "Surveying" so as to take charge of some, if not all, of the drawing of that department. He should be required to pass judgment upon the mechanical execution of the drawings for designs in the other departments.

The professor of "Roads, etc.," should take the courses in common roads and streets, tramways, railroading (theory and surveying), earthwork, tunneling, well-boring, dredging, railway management, estimates, and the management of forces of men.

The professor of "Mechanical Engineering" should take all the courses in machinery, excepting hydraulic and wind motors, and the courses in shopwork, foundry work, and mechanical engineering.

The professor of "Structures and Materials" should take all the courses in structures, and all those in materials except foundry work, also the course in foundations.

The professor of "Electrical Engineering" should take the courses in electricity, magnetism, thermodynamics, electrodynamics, and electrical engineering.

The professor of "Hydraulics and Sanitary Engineering" should take all the courses in hydraulics, marine engineering, sanitary engineering, and those in hydraulic and wind motors.

The professor of "Architecture" should take the courses in architecture and carpentry.

The professor of "Shipbuilding" should have only that one course.

The lecturer on law of contracts should also act as professor of English, giving occasional lectures (not included in the time schedule) on subjects connected with technical writing, and revising all these in respect to their literary character. A legal gentleman connected with the Patent Office, who would competently fill this chair, could readily be found. His work in the institution need occupy but a short portion of his time.

At the end of the five years' course a lecture of advice to the graduating class delivered by some prominent member of the profession would be of great value to the young engineers.

The author will now make a few remarks as to how certain courses ought to be taught. In some of the courses he has had a good deal of experience and consequently feels competent to speak thereon, in others he has had but little, and in still others none at all. It is this portion of the paper especially that he wishes to see thoroughly discussed.

The various courses in surveying should be thoroughly taught by textbooks (or failing these by lecturers), and sufficient field work should be given to accustom each student to the use and adjustments of all instruments and to acquaint him with the objects and *modus operandi* of each kind of survey. The location for the survey should be chosen so as to make evident its use, and the instructor should endeavor to organize his classes for field work in the same thorough manner as he would for an actual survey in practice. Strict discipline should be maintained in the field, and the students should be taught to obey orders as quickly and faithfully as if their positions depended upon their doing so. In short, all the operations in the field should be conducted in exactly the same manner as in engineering practice. The instructor should never employ old methods of surveying when new and better ones have come into use. Some of the latest and best methods can be found described in engineering journals and pamphlets only.

The keeping of notes is one of the most important points in surveying. The instructor should first ascertain the best method for each kind of survey, then explain it clearly to the students, and see that it, and no other, be scrupulously followed.

The instructor should acquaint himself with all the new instruments used in surveying, paying special attention to their adjustments, and should practice using them until they become as familiar to him as are the transit and level. He should then see that the students become as well acquainted with them as he is.

Concerning the best method of teaching the course in geodesy, and the necessary amount of practice therein, the author, having had no practice in that subject, does not feel competent to speak. The facilities for field work in giving this course are generally very poor; but the author would judge that a small amount of practice in base line measurement and practice in the measurement of a few angles of large triangles could always be given. For computations, the field notes of coast surveys might be taken. The class should have instruction by actual practice in all the calculations connected with a geodetic survey.

The courses in pure mathematics should be most thoroughly taught, and the instructor should explain the applications of the various formulæ as the course progresses. The course in calculus is generally given in such a blind manner that few students after finishing it know anything more about it than simply how to differentiate and integrate. They have no conception of the real meaning of partial and total differentials; and they could not possibly discuss a curve as given by the equation. If, during a purely mathematical course, the students be shown a little of the practical application of what they are learning, they will study with greater interest.

The subject of least squares should be taught both theoretically and practically, following the method given by Prof. Mansfield Merriman.

The amount of astronomy that an engineering student needs is not great, and the mathematical and instrumental portions of the course should be restricted to such investigations and manipulations as an engineer may be required to make.

The natural science courses of the first year should be of an elementary character, but those in the third year should be more thorough. The instructor should not forget the fact that it is not a class of physicists which he is instructing, but one of engineers.

The courses in drawing should occupy no more time than is necessary to give the students a reasonable amount of skill in the manipulation of the instruments. It is a mistake to spend much time on fancy shaded drawings, as in the last few years blue prints have driven elaborate drawings out of the field. The drawing department should be furnished with all the apparatus for making blue prints and similar copies of drawings, and each student should be thoroughly drilled in its use.

Pen topography appears to be a great waste of time, and it is to be hoped that the new mechanical method will soon supersede the old and laborious hand process. Meanwhile, it is probably necessary to teach a certain amount of it in engineering courses. Maps and plans should be always made in the most approved, practical manner. The course in descriptive geometry should be thorough, as the mental discipline acquired from it is of a peculiar kind and very valuable; moreover, without thorough instruction in this subject one would be unable to make some of the most difficult drawings that are required in engineering practice. But the portion of the course which deals with shades and shadows need not be very elaborate, because in these busy days there is no time for an engineer to indulge in such luxuries as shaded drawings with shadows. For the same reason no time should be wasted in the study of the higher linear perspective, the amount required for the entrance examination being sufficient for all practical purposes.

The instruction in the course in railroading should comprise all the operations of exploration, preliminary, location, construction, and maintenance, together with descriptions, by means of blue prints or other drawings, of rolling stock, station houses, tanks, trestles, culverts, and similar structures. After each student has had a little practice in laying out the various kinds of curves, borrow-pits, drains, slope-stakes, and grade-plugs, two suitable points should be chosen, say five miles apart, preliminary lines run between them, a location projected on paper, then run in on the ground, and finally the whole work should be completely laid out so that workmen could commence upon any number of parts of it at once. All the operations that would be performed by the section engineers in actual practice should be performed by the class, and each student should do enough of each kind of work to enable him to repeat the operations whenever occasion may require. Few, if any, engineering institutions give a proper course in railroad surveying, consequently, when a graduate first goes on a section he feels like a fish out of water, and is a laughing stock for the older hands. In this respect the author can speak from experience, having had to take charge of a section at the beginning of his professional career. Among other instructions he was told to drive grade-plugs for a cutting, and it was the first time he had heard of such a thing as a grade-plug. By a fortunate guess and by exercising a little common sense he managed to drive the plugs without exposing his ignorance.

Canal surveying should be taught in a similar manner to railroad surveying, and with as much thoroughness.

The courses in materials should be very extended, thorough, and practical. It is well to begin with an elementary work like Merriman's, then pass to a larger treatise such as Burr's, omitting from the latter all the mathematical work. Then take a mathematical treatise such as Wood's and investigate the actions of bars, beams, and columns under the various kinds of loading, returning afterwards to Burr's work for a more extended mathematical investigation.

The course in rational mechanics should be given just as thoroughly as are the courses in pure mathematics. Great stress should be laid upon the students' understanding clearly the fundamental and derived units and their interdependence. There is no satisfactory text-book for giving this course, but those lately written show a decided improvement upon the old ones. The course may be most advantageously given partly by lectures and partly by using text-books, Rankine's Applied Mechanics being relied on for the principal investigations.

The course in sanitary engineering should be given from text-books such as Latham's Sanitary Engineering, and the works of Waring, Philbrick, and others, supplemented by lectures which should comprise, among other things, deductions from the discussions on sanitary matters that have lately appeared in the technical papers.

In the shops the students should be taught to perform the most common operations in blacksmithing and carpentry, also the use of the lathe and other machine tools; and the instructor in mechanical engineering should bear in mind that he is teaching *civil*, not mechanical, engineering students.

The course in mining engineering should be short but complete, the object being to fit the students to take charge of the surveying and management of ordinary mines. If possible, some time should be spent in making an underground survey. Unfortunately, there is no good text-book upon mine surveying in the English language, therefore that part of the course must be given by lectures.

After completing the course in steam engines each student should be required to make a design for a small, simple engine, and prepare all the working drawings and an estimate of cost. Similar designs should be required in the courses in hydraulic motors, bridges, foundations, arches, and shipbuilding.

The only fit text-book for the course in hydraulic motors is that of Weisbach, but in respect to the proportioning of parts it is very crude, so that the course in this particular will need supplementing by lectures.

The best text-book for the course in wind motors is Wolff's. It is not necessary to make a design in this course, because windmills of any desired size can be ordered from the manufacturers without sending a single drawing or making a single calculation; and the chances that any member of the class will act as engineer for a windmill company are very small.

The course in bridges is an important one and is seldom properly given. The idea of most instructors appears to be that if they teach how to calculate the stresses in the main members in a truss, their duty is accomplished, whereas they have merely taken the first step. They should teach not only how to calculate every direct and indirect stress on every part of a bridge, but how to proportion all the parts to resist these stresses. Thorough instruction in bridge designing will greatly simplify for the students the courses in roofs, braced piers, and shipbuilding. It would be well to omit from the course all notice of those styles of bridges which have been disapproved by the leading modern American engineers, and no time should be wasted in figuring stresses in continuous spans other than swing bridges. In addition to the ordinary types the course should include suspension, swing, and cantilever bridges; and the students should be required to read a number of monographs of existing structures, for instance those of the Bismarck, Plattsmouth, and Niagara cantilever bridges.

The course in the theory of hydraulics should be both thorough and practical, and all antiquated formulæ should be dropped therefrom. Numerous examples for solution should be given the students in this course. Indeed, in all the purely technical courses as many examples should be given for solution as time will permit.

The course in foundations can be given most advantageously by the consultation system, the student being required to read carefully everything of value in the English language upon the subject. In choosing a design in this course the instructor should be careful not to make the work too long or too difficult.

The course in architecture should be of a somewhat elementary character.

After completing the courses in water supply and sanitary engineering, surveys of a small town should be made under the supposition that it is to be supplied with water and sewerage; plans should then be prepared, and detailed estimates of the cost be made out in the manner usually followed in actual practice when preparing to let contracts.

In giving the course in river engineering, special attention should be paid to the tried and proposed methods of improving the great rivers of America, and protecting the adjoining lands from floods. The course in harbors will necessarily be descriptive.

The course in shipbuilding, though not occupying a very long time, should be complete; and special attention should be paid to details and the proportioning of parts to resist calculated stresses.

The course in law of contracts must of necessity be merely elementary, still it should be sufficient to enable the members of the class to prepare any forms of contract that will be needed in engineering practice.

In any course whenever models can be advantageously employed as aids in instruction, they should be provided and used. Moreover, they should be intelligently designed and properly manufactured, for an incorrect model will have a prejudicial effect upon students' minds instead of being an aid to understanding.

Students should be encouraged to take exercise; but excess therein should be avoided for two reasons; first, there is always a tendency to overdo such sports as football, rowing, and racing, thereby losing instead of gaining health; second, there is usually a great deal of time wasted. For instance, in rowing it generally takes quite a while to get to and from the boat-house; and baseball matches require a great deal of practice and occasional excursions to neighboring towns and colleges. For good, healthy exercise that is not liable to be overdone and that requires the minimum loss of time from work, affording at the same time plenty of amusement, there is no out-of-door sport that can be compared to lawn tennis; and if the grounds belonging to and surrounding the institution be laid out into tennis courts and maintained in good order at the expense of the institution, it is highly improbable that the students' health will suffer from lack of exercise. If the grounds be large enough, spaces for baseball and football might also be allotted.

A gymnasium is a useful adjunct to an institution of learning, and room might be provided therein for private instructors to give lessons in fencing, boxing, etc., to those who have the time, money, and inclination for such pastimes. Students should be encouraged and taught to look upon the taking of exercise as a necessity for health; but it must be remembered that, unless the exercise be presented in an attractive form, few will have the moral courage to take it.

Technical degrees are not looked upon with the proper amount of respect by the world at large. This is due to two reasons; first, there is no law to prevent any man from tacking a C. E. or an M. E. to his name, consequently, it is no uncommon practice for rodmen, surveyors, and mechanics to thus dub themselves engineers; second, there are too many low-grade colleges in the United States giving engineering degrees without a proper engineering education. The institution which would give the ideal course previously described might obtain legislative permission to have the sole right to confer the following degrees, viz.: B. C. E. (Bachelor of Civil Engineering) to the members of its graduating classes, M. C. E. (Master of Civil Engineering) to graduates who have had five years' practice and who have passed a rigid examination upon some special branch of engineering optional with them, and the honorary degree of D. C. E. (Doctor of Civil Engineering) to those graduates who have distinguished themselves in their profession.

The trustees or managers of this institution should give all the encouragement and aid that lie in their power, to promote original research by the professors and assistants. They should see that the institution be properly provided with an abundance of good books, drawings, and models, and they should encourage the formation and maintenance of scientific societies connected with the institution.

The officers of the institution should not exercise any control over students, except when the latter are within the precincts of the institution, or in cases of grave offences against either the law or individual welfare; and no religious exercise of any kind should form a part of the curriculum.

LETTERS TO ENGINEERING NEWS

DISCUSSING

"CIVIL ENGINEERING EDUCATION."

CIVIL ENGINEERING EDUCATION.

DISCUSSION.

By Prof. Wm. H. Burr.

My contribution to the discussion of Professor Waddell's paper should rather be termed a discussion of his subject; as some of the general characteristics, only, of what seems to me to be the engineering education best adapted to the present demands, will be considered.

A close observer of the present condition and requirements of the "profession" of civil engineering cannot, I think, fail to conclude that the schools now existing under that name do not supply some of the higher qualifications frequently required in engineering practice. A very few schools offer fair opportunities for the acquisition of the purely technical portion of the education under discussion, but they are utterly without that broad and general training which, in after life, develops into influence and power over men.

The difficulties which surround the proper organization of such a school of civil engineering in this country are neither small nor few, although, as will presently be seen, means are at hand for the effectual remedy of at least one great difficulty.

In the first place, there must be educational institutions, in which young men may be prepared in the more elementary portions of those mathematical and physical lines of study which are to be more extensively developed and pursued in the various ramifications of technical application in the school of civil engineering. Again, in these schools, preparatory or introductory to the advanced technical establishment, there should be found complete courses in the science and use of languages, and kindred subjects, which constitute the humanities of an ordinary college course. In order that a civil engineering school may be organized for the best practicable results, and at the same time fall short of being purely ideal or Utopian, it is not too much to say that such introductory institutions should be available—and, indeed, they are available.

A few young men yearly already possess the wisdom to first take a college course of study, and subsequently devote their attention to the school of civil engineering. This is motion in the right direction, and indicates that the conditions are even now favorable to the highest attainments in technical education. It has thus begun to be perceived, that not only the higher success in civil engineering is not to be reached by a purely technical training, but, also, that the best engineering education is to be based on, and preceded by a thorough training in those general subjects which cultivate and expand the intellect, and give a young man the broadest base and surest foundation for the subsequent structure of his after life.

It must be carefully borne in mind that a successful engineer is not only a successful technist, but, also, a successful man; and a successful man is one who in his business and other relations controls men. The inception, development and culmination of an affair involving engineering work may truly require the most complicated and subtle application of technical knowledge, but unless the engineer is simply an employee paid to exercise his art as a technist only, he must be cultivated in those accomplishments of intellect and address which shall give him power to sway the minds and judgments of those about him to his particular purpose. In the first case he attains, it is true, a most creditable success in his specialty, but in the second only is he a principal, and does he attain success as a professional engineer.

The highest type of civil engineering education, therefore, is one in which the broadly cultivated intellectual powers operate on and assimilate technical knowledge to the end that the individual may not only convert the powers of nature to the use of man, but, also, convince man of the utility of nature, i.e., it should fit him to move both man and nature.

The better colleges with fixed and not elective courses may answer tolerably well the purposes of the schools preliminary to that of civil engineering. They, however, go too far in some respects and not far enough in others, so that unless a young man is well directed and advised, he will fail to get enough of physics and mathematics and too much of the dead languages. Not that I think the latter should be ignored, but that the student ultimately destined for civil engineering can best confine himself to Latin alone. A good knowledge of that language will give him greater power over his own, and render his acquisition of at least one important modern language easier and more thorough, besides incidentally conveying to him some historical knowledge, which will form no contemptible portion of his general education.

With the purpose of indicating the availability of the colleges of this country in the best scheme of technical education, I suppose them to supply elective courses, which many of the best are already doing. In such a manner, and in such only, can they perfectly and most admirably supply the required educational training preliminary to the technical school. All time ordinarily prescribed for Greek should be devoted to the most careful and thorough extension of the mathematics and physics found in ordinary college courses. In this manner, advanced or higher algebra and analytic geometry, as well as the elementary portions of descriptive geometry, would be completed with the end of the student's college work. An excellent foundation would be laid in heat, electricity and magnetism on which would afterward be founded advanced technical courses. Light and sound being less essential to the civil engineer, would be finished at college. Some fundamental notions in chemistry should also be given. The complete college curriculum, so far as all English subjects and the French and German languages are concerned, should be most scrupulously adhered to, since these form, or should form, the immediate, if not main, purpose of the student's time at college.

If a young man can by any possibility spare the time and means, four years should be devoted to this preparatory season. If any misfortune prevents this, the omission of Latin and partial or complete curtailment of either French or German will enable him to complete this preliminary work in three years without directly or immediately impairing his technical preparation. Only the direst necessity, however, should induce him to thus reduce his general education, and he should improve every possible opportunity subsequently to repair the loss.

This simple and very incomplete sketch outlines a field of the highest usefulness for the modern elective college curriculum. Among its most important possible results not one is greater than its preparation of the technical student for his technical school.

No student of civil engineering should enter the elective college under sixteen years of age. He would then reach his technical work preferably at an age not less than twenty years, or with the curtailed elective course at the age of nineteen years, and thus begin the study of civil engineering proper with a fixed purpose and habits of work settled both by discipline and advanced years as a student. His college experience would give him such facility of analysis and power of comprehension that both the quality and quantity of his subsequent technical work would be greatly increased, while the breadth of his preparatory training would in all cases completely counteract any narrowing influence of his purely technical study and investigation; and there now only remains to determine in a general way what that shall be. I believe Prof. Waddell has in the main most admirably settled this part of the question. In continuation, however, with what has preceded, I would limit the course in the civil engineering school to three years and place many of his first year subjects in the elective college course; such, for example, as Analytic Geometry and Natural Sciences. In the writer's opinion, also such subjects as Mining Engineering, Mechanical Engineering, Electrical Engineering and Ship Building should be omitted from a course in Civil Engineering, as here contemplated, as not sufficiently germane to the subject. It is believed the same may be said of Foundry Work and Pattern Making as well as Architecture, unless the later be composed of some very fundamental notions which would enable the engineer to utilize properties of materials and constructive principles so as to produce outlines of good engineering structures and features of sound construction, without violating the canons of good taste.

It would certainly be useful for a civil engineer to be familiar with the subjects just criticised, but he is human and correspondingly limited in his capacity to work, and in these times of specialization he cannot practice as a universal engineer. He will find it sufficiently difficult to perfect himself as a civil engineer, and he should concentrate all his technical efforts in that direction.

It is also a very grave question how far shop-work should enter the course in civil engineering. It is certainly true that such a course of study may be founded without a trace of shop-work in it, and yet be productive of excellent results, for actual test has demonstrated the fact. No civil engineer needs facility in the use and manipulation of tools and machines, or in foundry work and pattern making, but he should understand their capacity. Whether actual experience in shop-work is necessary to enable an educated and intelligent man to determine what shapes for an intended purpose can be most economically produced, or, sometimes, produced at all, may possibly be a matter of opinion, but I am confident that experience is not necessary. Proper lectures on the use of tools and machines, illustrated and enforced by constant references to models and drawings of metallic structures showing the members shaped and surfaces finished by them, together with frequent and careful studies of the same tools and machines at work, not on models or specimen pieces, but on actual members in process of production in accessible shops and foundries, will supply just the knowledge of these principles, both in quantity and quality, which properly govern design. While I am aware that clinical lectures of the mechanical kind are not in some quarters considered of much value, I am confident that these careful and well-directed shop observations, supplemented by proper lectures, are productive of every desired result.

With the modifications just indicated, and with the purely technical part of Professor Waddell's curriculum applied to a three years' course supplementary to the elective college work covering four years, I should consider this civil engineering study extending over seven years no more complete than professional requirements now demand. A young man would then be ready to begin his practical life at the age of twenty-three years, which is but little, if any, in advance of the average age of the graduates of one or two of the best of our technical schools.

It may be objected that the preceding scheme is too elaborate, that the great body of average young men cannot be expected to attain to such a high professional grade as is contemplated in this broad and extended scheme of education. All of which I admit, and more. But it is undoubtedly true that the highest success in civil engineering, as now constituted, demands even more of an educational foundation than that here outlined; and it is equally true that a complete technical course of study should be so designed as to develop the best men in the best possible manner. In the midst of such general excellence the average man, by the force and example of his environment, will be brought to the highest possible stage of development; much higher, in fact, than in a system of less general merit. Again, with such an admirable educational system, the responsibility of failure rests not with the institution but with the individual.

Let it not be supposed, however, that I for a moment imagine the result of such a course of study is the finished civil engineer, who is really the product of ability and adaptability combined with years of experience based on the broadest and best educational foundation.

For this reason I can scarcely command language strong enough to condemn the present practice of conferring the degree of "Civil Engineer" at the end of a frequently and usually meager course of study. Whatever may have been the intent in its origin, in its present practice it is almost universally little else than a bid for patronage. Certificates vouching for the amount and quality of work done may with propriety be given at any point in the course, but the degree of "Civil Engineer" should only be given after the satisfactory completion of the entire course of study, supplemented by at least two years of actual experience in engineering work and on the presentation of a creditable thesis.

The organization and administration of such a three years' course in civil engineering as has been outlined may be satisfactorily completed in a number of ways, and it will be advisable to touch on some main features only.

Whether the corporation should be "the President, Fellows, etc.," or "the President and Trustees, etc.," is of little matter, but it is of vital importance that there should be no "one man power" about the educational part of the establishment. Among all vicious features, a self-constituted autocrat with little greatness and great littleness probably stands pre-eminent, and such a millstone about the neck of a worthy institution is not unknown. Able men with strong character, competent to fill a professorship, and with a corresponding amount of self-respect, need not and will not quietly serve under such circumstances. As an inevitable consequence, lack of harmony or vacant chairs will result; and both are highly objectionable.

The head of the faculty may possess the veto power, but he should use it with the greatest discretion. In other respects, so far as the curriculum and educational discipline are concerned, he should simply be the executive officer of the faculty. There should be frequent stated meetings of the faculty at which heads of departments should vote and the result should be final. Lectures, recitations, and examinations should be conducted in the broadest possible spirit. So far as the methods of instruction are concerned little need be said, for if an instructor is competent to fill a chair in a faculty of civil engineering, methods may safely be entrusted to him. If such responsibilities are not safe in his hands he is unfit for his position and should be promptly displaced in favor of a competent person. The same effective measure of reform should be applied if by any unfortunate appointment a chair is found occupied by an instructor who allows his whims, his narrow ideas, or, worse yet, his spite, to govern his ordinary exercises or his examinations. This evil is by no means imaginary, and it is known to exist in connection with mistaken ideas which restrain the proper authority from exercising its remedial power of removal.

"Fellows or Trustees" should understand that the educational discipline of the institution and details of the course of study can only be effectively reached through the faculty; hence their direct interference will inevitably bring disorder and almost as inevitably increase the difficulty intended to be remedied. It is their duty to see that pröper men are in the faculty to conserve such matters, and to remove without delay such as are disinclined to discharge the duties and responsibilities of their positions.

By Alfred P. Boller, C. E.

Without undertaking to cover the whole ground embraced in Mr. Waddell's paper, the fruit of careful study, backed by a post-graduate experience, there are certain points on which too much stress cannot be laid and which I desire to emphasize.

1st. The standard of admission to technical schools should be raised, especially in the department of belles-lettres, in which now next to nothing is required. English studies, composition, grammar, geography, history, etc., are out of place in a special school for technical education—a preparatory department would be a good adjunct to such schools, where a young fellow could get a fair training in studies of general culture.

2nd. The elaborations of the higher mathematics should not be carried beyond reasonable proportions, since the great bulk of students will never have any use for their application. Their time can be more profitably employed in the application of practical mathematics to the practical problems required in the performance of actual work. Opportunity, however, should be afforded for the specially gifted or inclined students to pursue mathematics as high as they choose to go. Mathematics carried up to the point of a full knowledge of the Theory of Elasticity, and the necessities of Coast Survey Geodetical operations, would be as far as should be compulsory for the average student. Over-development in mathematical refinement is apt to lead a student astray in the belief that engineering is an exact science, whereas it is in a large part the application of common sense, tempered by varying conditions of a physical nature or commercial necessity.

3rd. Some attention should be paid to the principles and practice of architecture, as essential to correct design, engineers as a rule being deficient in a knowledge of taste in building construction, or what constitutes appropriateness or fitness in mass, proportion, and color. Other things being equal, they should know on what principles to select that which is most pleasing to the eye, and appropriate for a given purpose in view.

4th. Thoroughness is essential—a special school must live upon its reputation, and not be prostituted for the purpose of securing a large income. No student should be progressed, much less graduated, without having performed satisfactorily all the work assigned for him to do. An institution will soon lose its standing when it relaxes the enforcement of its avowed requirements, to say nothing of the resulting injustice to its students, and the loss of that "something" which the French call *esprit*, so vital for "a long pull, a strong pull, and a pull altogether," in one common interest.

5th. No matter what system may be adopted, its working, after all, is in the hands of the corps of teachers, and their individuality is more or less stamped upon its mode of application. The best devisable system will turn out the poorest kind of results if in the hands of inefficient or inexperienced teachers. Teaching does not consist in hearing a lot of recitations, but in an intelligent enforcement of principles with their logical bearing upon a given end in view. It is therefore of the first importance to make such pecuniary inducements, either in the way of salary or outside opportunity, as to secure capable professors. And this is just wherein consists the practical difficulty of the whole subject. Engineering being peculiarly a profession of applied science, men successful in its pursuits can hardly ever be tempted to become teachers, even if fitted by temperament to such work. It has therefore been the custom to take young men fresh from graduation and make them professors in an active profession of affairs which they have never practiced. I must confess to an inability to see how this system can be materially changed. It may be tempered by a system of outside lecturers, active members of the profession, upon practical topics, who can give very many valuable ideas or suggestions that would be of great service to the students in after life.

6th. The director of the technical school is the fountain head of its administrative and educational methods, and no pains should be spared, and every inducement offered, to secure the right man for this vital position. Few men are gifted with the grace of character, social relations, experience, intellectual training, and diplomatic interest that an ideal director should possess. A near approach can only be attained by sufficient salary inducement to tempt those best fitted for the position, and I would regard $6,000 per annum none too high for such a man.

It must not be forgotten in discussing this subject that no school can make engineers—it can at best give the student only a ground of engineering science, that will enable him to rise more rapidly in the world when once in contact with actual practice. The engineer is born and not made, and only the true engineering instinct will even rise beyond the general ocrity.

It is a mistake, in my judgment, to give diplomas at graduation, as is now done. The degree of E. S. or M. E. should be carried by a post-graduate record, the certificate of graduation being all that a student should receive, after completing his technical course. The degrees would be prizes still to win, and worth something when attained.

Extract from a Letter by G. Bouscaren, C. E.

The first requisite of an engineer is accuracy. I am sorry to say that, within my personal experience, very few graduates possess this quality, not from the want of natural ability generally, but from the fact that they never acquired the habit of checking their work. This faith in the infallibility of the mind works disastrously in an engineer's office.

"Error is the rule, truth the exception." These words should be written in epigraphic form in all lecture and study rooms of engineering students; they should be taught that the simplest operation should be proved before accepted as correct.

I do not see in Professor Waddell's curriculum any mention of methods of approximation as applied to the ordinary practice of engineering; this is certainly a great desideratum for the training of the judgment of the average young man who reads his rod to the 1-1000 part of a foot on rough sloping ground and neglects to check his bench, and who is content with an unverified assumption of load on a structure, but will carry out the stress on each member to a fraction of a pound.

The majority of American graduates are very deficient in the art of draughting—wherein they stand in dreaded inferiority to their European brethren, who for this reason only will often beat them in the race for positions. It is a great error to suppose that the introduction of the heliographic printing process has much decreased the demand for good draughtsmen. This printing simply saves the time and labor of "tracing machines," but it does not design details or produce the carefully drawn graphics which should always serve as a proof for analytical calculations.

Although proficiency in draughting is not indispensable to the success of an engineer if otherwise well gifted, it is an advantage which he cannot afford to throw away and which should be given by all good technical schools.

By W. H. Booth, C. E., Manchester, England.

The field of engineering is now so extensive that no man becomes really an expert in every branch. Still it would appear that a breadth of education is necessary to every engineer even should he be intending to become a specialist. The great fault in engineering education has hitherto been the neglect of practice, and students of engineering may be found who are steeped to the lips in text-book learning and yet who have no ideas of a practical nature and would find it difficult to apply their knowledge to a practical case, and even when they endeavor so to do they evince so much ignorance of facts necessary to be considered that their designs are very faulty. An engineer should certainly be trained in something further than mere theory so-called; practical knowledge should be acquired, and to both should be superadded at least a knowledge of materials and market prices, without which no engineer dealing with contracts can be held efficient. Ignorance of practical detail and neglect of common-sense precautions are usually made apparent in specifications and working drawings, which show to the real engineer the ignorance of the man who drew them up. An example of this may be cited. An engineer to a large corporation put out a design and specification for a structure on a pile foundation. He had obtained borings of the site, and probably, to his own satisfaction, came to the conclusion that the piles should attain a certain penetration. This he specified, and his drawings, nicely colored, showed the finished piling all driven down to one level. What were the practical results? It turned out to be impossible to drive piles, of the soft timber specified, to within about half their length, for the ground was hard and unyielding and proved one in which piling was really unnecessary. The Inspector or Clerk of Works appointed did not understand his job, and compelled the contractor to drive for an unnecessary time. The result was that almost every pile was split from head to toe and no further penetration obtained. Money was wasted because, though he recognized clearly his mistake, the engineer had not the courage to alter his plans.

In another instance of a similar structure designed by an engineer who could realize existing facts, it was specified that no timber be ordered for piling until it has been proved, by actual driving, at the four corners of the foundation and other parts, of some dozen trial piles, what penetration was really necessary and possible. The result was that timber was bought to correct lengths, that each pile was put down to a bearing stratum and in a sound, unsplit condition, and while the first engineer added nothing to his reputation, the second at least lost nothing, and obtained a cheaper and better work. It is on account of such errors that so much of the ill-will felt by contractors toward certain engineers arises, and attempts at scamping are made. An engineer's education should fit him to be a man of courage; he should do his best to avoid errors, but when an error has been committed he should not act the coward to the extent, which his specification and contract probably admit, of throwing the brunt of the loss upon a contractor. This is commonly done, however; but an engineer who will not manfully own up to his own mistake deserves to be drummed out of the profession to which he is a disgrace.

In the knowledge of materials and market prices, too, engineers are sadly lacking, if one must judge by the qualities of the materials they specify, the sizes and sections shown on drawings, and the prices at which they will accept work. If an engineer understands prices he will know, when a tender is submitted to him at a cost less than that of the raw material, that either the contractor has made a mistake, or does not intend to do an honest piece of work, or is making a sacrifice to obtain a footing, or perhaps has a stock of material to be worked off. Now, though it may not be the duty of an engineer to save a contractor from loss, and it may be his duty to accept the lowest tender, he should have such a knowledge of costs as will show him that below a certain figure a fair and honest piece of work cannot be done at a profit, and unless satisfied that there are good reasons for so low a tender, he should refuse to accept such a one as leading to greater expense and trouble in the long run.

Professional etiquette ought to be a portion of every young engineer's education. He should be taught clearly and plainly that when acting as engineer he should not soil his hands in trade. I do not mean by this that trade is low or mean, but that when mixed up with contractors he should avoid partiality for certain manufacturers. Contractors too often find, after they have signed a contract, that the engineer expects them to go to certain parties for their materials, and by doing so they have to pay perhaps 20 or 30 per cent. more for their stuff than the price on which their tender was based. If they purchase where they choose they speedily find that no matter how good may be the material, it comes in for condemnation, and the Clerk of Works refuses to pass work, however excellent, because he knows that this will please the engineer.

When special manufacturers are desired, this should be plainly stated in the specification and enforced in carrying out. The silly clauses of specifications, too, ought to be expunged; they may be thought by some to denote care and excellence, but clauses which specify impossible virtues in timber, qualities of iron for bolts, etc., which stand at such a price that no contractor would dream of putting them in his tender, are mischievous and should be avoided.

The foregoing may appear, to some, out of place in a discussion on technical education. How really important the points named are is keenly appreciated by many who have suffered from the ignorance of them. The ignorant engineer is a worse man to deal with than the strict and learned one. His ignorance prevents him from making any concession to changed circumstances, for he knows not how much to concede or how little.

In proving the knowledge of a student by written examinations, it appears to the writer that these should not be the over-shadowing events which they usually are in England.

As the period of examination draws near, there is always an air of excitement about a college. Nervous students, often the ablest men, feel as though execution were at hand and probably fail miserably. Frequent examinations should be held; they lose their terrors in this way and are then far truer indexes of comparative ability.

The choice of text-books is one intimately connected with the practical training of an engineer. These books should be something more than a mathematical exposition of principles. The works of Rankine, for example, are good as far as they go, but they are not suited to be put into a student's hands alone. The man who takes Rankine's works and adds a practical appendix or design to each chapter will do a valuable service. The engineer who is best able to appreciate Rankine is the one who has been in practice for some time.

A student ought to be early taught to associate theory and practical design. American books, more than others, are examples of what students' books should be. A simple mathematical course of instruction in framed structures with fancy diagrams carrying suspended weights marked W has neither the interest nor the value to a student which is possessed by the same course applied to a practical example which may be a roof or bridge in the neighborhood. The difference between the actual structure and dimensions figured out by the class may be made useful in showing how the design has been modified to suit material, or even to indicate a possible lack of economy or a want of appreciation of some factor which should have entered into the designer's calculations.

In the matter of models it cannot be too clearly impressed on the guiding authorities of a technical college that those should be, as Mr. Waddell remarks, intelligently designed and properly manufactured.

The writer has now before his mind the boiler-house of a very celebrated college. The house is inconveniently and badly designed; the boilers it contains are very far from being examples of good design, while the engine-house close by is too small to allow two men to pass comfortably into it. The whole is a sample of what to avoid; yet students from that college will, many of them, have few or no opportunities of seeing other and better designs, and may, in distant colonies, have this model in their memories if called on to design a steam plant.

The thorough course of study laid out in the paper is excellent, but there are many who have in them the making of good engineers that cannot afford such a course. Still, for such as can afford it, an education thus gained would be a far better return than such as can be obtained by the prevailing custom of paying a heavy annual premium for the privilege of sitting on a stool in the office of a great man who never interests himself in his apprentice and teaches him nothing. Such a course is simply ruin to a young man who has not the courage to insist on being properly employed on works.

In the matter of manual work is chiefly found disagreement between those who, believing in special education for an engineer, are of different opinions as to the nature of such an education. Some insist that the engineer should be as good a workman in every branch of trade as any who may be under his authority, but this is clearly impossible. To acquire a workman's skill in dealing with timber, iron, and stone, not to mention bricklaying and numerous other allied trades, would occupy years, and though clearly of advantage to any engineer, is not reasonably possible. As well demand that the surveyor of a railroad be able to take the lead of the most powerful navvy in wheeling loaded barrows. Indeed, it appears likely that a series of good workshops, each with at least one first-rate tradesman attached to the college, should be sufficient in teaching the practical art, though the rate of work is best learned by actual experience in some manufacturing concern, as also are methods of conducting work. In the workshop of the manufacturer, too, are best learned those essentials to economy which embrace the utilization of, say, one pattern for several sizes of machine by very slight alterations of the pattern. The casting of both cylinders of a locomotive from one pattern is a case in point. Such workshop experience, however, need not be of great duration; a man of ordinary intellect will soon grasp the ideas necessary—knowing for what he is seeking.

In imparting instruction the instructor should not allow students to forget what it is they are there to learn, and he should aid them rather by hints than by direct help.

When under examination it appears unreasonable to withhold common pocketbook information, such as weights per cubic foot of the different materials dealt with in the question. If withheld for the purpose of evolving the knowledge of the student on such points, those who cannot recollect these numbers and other coefficients should be allowed to assume values, for, in practice tables of these values are always at hand, and to refuse them is to condemn often the best men to failure, and to favor a system of cramming which is injurious; when a student understands principles he may be trusted with materials, but formulæ in the hands of him who does not understand their signification are hurtful. The great aim of all teaching should be to lead a student to apply true principles to work.

By Prof. Geo. F. Swain, Massachusetts Institute of Technology, Boston, Mass.

The paper of Professor Waddell is without doubt the most valuable contribution to the subject of Civil Engineering Education that has yet appeared, and no one can read it without obtaining many valuable hints, although he may be obliged to differ with the author on some points. I am glad to have the privilege of expressing some views in regard to what a course in civil engineering ought to be. Professor Waddell has arranged an ideal course, which would certainly be thorough, but which is unfortunately impracticable and not adapted to the conditions in this country at the present time. One of the principal difficulties that higher schools here have to contend with is the lack of proper preparatory training in the students and the want of uniformity in preparatory schools generally. An applicant for admission may be able to pass the entrance examinations and yet be far from qualified to pursue the course to the best advantage, and vice versa. If a school were so fortunate as to be financially independent of tuition fees, it might raise the standard of admission by one or two years, and with that as a basis arrange, as Professor Waddell has done, an ideal course of five or six years, thus adding practically two or three years to the courses now generally given. But the writer does not believe that such a course would be at all advisable. In the first place, the number of students seeking such a school would be small, considering the present condition of our preparatory schools, and the institution, under this arrangement, would not be doing the work in the community that it might. In the second place, the greater number of engineering students, judging by the writer's experience, are young men who expect to be obliged to earn their living as soon as they graduate, and who desire to complete their course with as little delay as practicable. Those who form the exception to this statement would be the ones who would perhaps seek a school giving a more extended course. Now, the writer believes that a rather better plan than Professor Waddell's, and one which enables the school to cover a much wider field of usefulness, while in no wise impairing its capacity for teaching advanced subjects, is the one by which, with requirements for admission corresponding to what is attainable in the ordinary preparatory and high schools, the regular course is made to cover four years, while advanced courses, leading to advanced degrees, may be pursued by students having time and inclination. This is the general plan now followed by several leading institutions. These advanced courses, however, should be carefully laid out, and provision made for teaching every subject of importance.

It must be remembered that there is a limit to the amount of detail which it is in general advisable to teach in a school, depending a good deal upon the character of the students, and whether they have beforehand had any practical experience. The average age of students entering the higher schools, judging from the writer's experience, seems to be not far from nineteen years, and there are many students who afterwards make excellent engineers, who obtain in four years about all that they could profitably get in a school, while there are many things that it is far better for such men to learn after they graduate. Students who desire a more thorough course, and older students who have had some experience, should be able to get all they desire in the advanced courses.

These views, however, are based on the assumption that the regular four-years' course is rather differently arranged than is now usual. Many institutions are now, and have for years, been engaged in an attempt to crowd into four years what would naturally occupy five or even more, either by resorting to a process of mental compression or by treating the various subjects very superficially. In the former case the effect upon the student is very similar to that produced by an overloaded stomach, and the superfluous material is very soon thrown off without having been of any benefit to the organism; and, in the latter case, the student's conceit is usually developed at the expense of his brains. Some remedy for this is imperative, and the plan which seems most promising to the writer is, first, to omit from the course such studies as will in after life be of limited practical importance to the student (such as higher Chemical Analysis, Zoology, Paleontology, Crystallography, etc., from a course in Civil Engineering), and, second, to introduce options into the course. In the Massachusetts Institute of Technology it was found necessary years ago to omit from the civil engineering course many studies which are taught in some other similar schools, and thereby to obtain more time for professional work; and the results have been very gratifying. It had been found that within a year or so after graduating the students had entirely forgotten whatever they once knew of such subjects as those above enumerated, and as for the training they give, it was considered that it could be much better obtained in more purely professional work. In the same institution the use of options has been within the past year very extensively introduced, and students, while required to take a certain—and, indeed, a very considerable—amount in each of the branches of civil engineering, are now allowed, if they choose, to pay particular attention to some one branch, and to devote proportionally more time to it than to any other. It not seldom happens that a student knows exactly what branch of engineering he is to pursue in after life, and this system enables him to fit himself particularly in that direction, while a student who is uncertain what his future will be should have a general course embracing all branches in about equal proportion. Prof. Waddell has well alluded to the rapid specialization of engineering, and in view of this fact some such system as the above seems to the writer imperative; at the same time he should not be understood as advocating a narrow training. A course in civil engineering should be very carefully laid out so as to avoid this, by one familiar with teaching and with the needs of the profession; and it should be very carefully balanced. A proper course of this kind requires more instructors than one of the old kind, but it also has the very great advantage that each instructor may be a specialist, and his instruction all the more valuable on that account. One man cannot well teach all the branches of civil engineering with any degree of thoroughness. The thing may be set down as a practical impossibility, and the more instructors the better the instruction will be.

As regards methods of teaching, Professor Waddell has covered the ground so ably that little more can be said. The subjects, or matter of instruction in schools, may be divided into two classes: the first includes those things, such as mathematics, mechanics, etc.—in fact, those things commonly called theoretical—which the student will probably not learn at all, or very imperfectly, unless he learns them in the school; the second includes chiefly matters of practical detail, or those things which the student must learn if he is to succeed in practice, and which in many, if not in most cases, he can learn better and more quickly out of the school than in it. Now I take it that nobody will deny that the first class of subjects—the principles of engineering—are the things which first and foremost should be taught, and taught thoroughly. The others should be taught as far as there is time for them. Of course there are many things, such as surveying, of which the principles are best taught by teaching the practice, and of this an engineering graduate should have a very thorough knowledge, but we are dealing now with generalities, and need not go into particulars, as there is no danger of being misunderstood. But I hold that in teaching principles they should be taught in connection with the practice. Copious illustrations from practice should be given, and the student should be made to see the practical bearing of everything he learns. He should not be allowed to look upon his mechanics and mathematics as entirely independent of and distinct from his practical work, but he should be trained to see their connection. Only in this way, the writer believes, can the student be made really to understand and appreciate and remember what he is taught. In connection with hydraulics, measurements of flow should be made in some stream or mill flume, and excursions should be made to hydraulic works, and to cities such as Holyoke, Cohoes, Lowell, etc. In connection with bridges, visits should be made to bridge works, if at hand, or to bridges in the neighborhood or in the process of erection. And the very best way of enforcing this method is by actual work in designing, so well emphasized by Professor Waddell. The writer is fully convinced, from his own experience, that there is nothing like it as a mental training for the engineer, as well as an aid to the student in understanding and appreciating the value of his principles. Rightly considered, there is no gap between theory and practice; the two must go together. There is no theory which is worth anything which does not take account of actual conditions of practice, and there is no practice which is worth anything which does not, when necessary, make use of the proper theoretical considerations. This the student should be made to see.

It is further very important to teach the student accuracy and, as far as possible, originality. There is no better way to train him in accuracy than by practice in designing, especially in bridge designing; and originality may be fostered by proposing new problems or examples, and getting the student to think for himself, though there are some men who seem to have no power of doing anything that they have not seen done before.

There is one thing to which I think the author of the paper has not directed sufficient attention, and that is to the study of English. In this respect technical schools labor at a disadvantage, and not being able to devote much time to English branches, it often becomes the feeling of students, and sometimes of instructors, that these are of little importance.

No idea could be more erroneous. The engineer who can write a good report, who can express himself, clearly and tersely, and who can spell correctly, will have a great advantage over one who has not these acquirements, and proficiency in this direction should be vigorously striven after. On this account the writing of abstracts, reports on various subjects, vacation memoirs, etc., should be introduced as far as possible. In the experience of the writer very good results have been obtained by requiring the students to examine and report on some engineering structure, or on the sanitary condition of a small town, the disposal of its sewage, or the plumbing of some large building. It is, nevertheless, true that until our preparatory schools do more and better for us in this direction, we shall not be able to accomplish as much as is desired.

Neither can I agree with Professor Waddell in his remarks about modern languages, or in his statement that any work of real value in French or German is very soon translated into English. It is no doubt true that many students leave our technical schools after having studied those languages for years, and yet without the ability to read a book in either of them. This, however, simply indicates a fault in the method of instruction, and I think many improvements remain to be made in this direction, particularly in technical schools. The instruction in French and German should not be left wholly to the teachers of modern languages, but should be taken hold of by the teachers of engineering themselves. The students should be made to appreciate the fact that much of the best literature is in French and German; the technical periodicals in those languages should be put into their hands; they should be made acquainted with the vocabulary of engineering terms; required to make abstracts of important papers, and in this way fairly initiated into the use of the language, and their interest in it, from a technical point of view, aroused. In this way excellent results may be attained.

The author's remarks about text-books, examinations, lectures, etc., are very good. Every teacher of experience will doubtless have found a combination of methods of instruction advisable, depending upon the character of the subject, the time at disposal, the number of students in the class, and other matters. I am inclined, however, to attribute much more importance to the lecture system than is done by Professor Waddell, provided the students are instructed in the taking of notes and required to keep their note-books ready for examination. A competent teacher can in one lecture give the student information that he would be obliged to search several books, perhaps in foreign languages, to obtain; he can in a course of lectures give the students, in many cases, the meat of the subject in a way in which he could not obtain it elsewhere; and he can duly compress or expand the subject with reference to the time of disposal. Professor Waddell's method of requiring the students to read a great number of books, or "everything of value in the English language upon the subject," appears to the writer most decidedly uneconomical of time and energy (except for the instructor), if not impracticable, and I believe much better results will be obtained in the same time by covering the subject with a well-prepared course of lectures (if a suitable text-book is not at hand), and spending the remainder of the time which Professor Waddell would devote to reading, in designing or similar work. The writer's practice is to have his notes printed in abstract for the use of the students, who are thus enabled to pay attention to the lectures while in the class-room, and relieved in large measure from taking notes. The lecturer can expand the subject to any extent he desires, and the student, with the printed book to guide him, and a few notes taken by himself, is enabled easily to complete his notes afterwards. He is still required to have a note-book ready for examination at any time. Nevertheless, the fact remains, that the lecture system is best suited for the higher classes, and that for the lower ones the use of some good text-book, where there is one, is preferable. Professor Waddell believes in informal lectures; the writer thinks that all lectures should be to a large extent informal, and that the students should be continually encouraged to ask questions freely at any time.

The author's remarks regarding examinations are excellent. As to the ordinary method of written examinations lasting three or four hours, there can be no question of its inadequacy, and to grade or judge students solely thereby must often be accompanied by great injustice. Oral examinations do not seem to the writer very much better, though he has never tried them extensively; to him the only method seems to be to hold intermediate examinations at intervals, and to take due account of the recitations and general behavior of the student during the term.

The course of study laid out by Professor Waddell is an entirely imaginary one, and may be said to be impracticable at the present time and with our present preparatory schools. A student going through this course would certainly have no cause to complain of its incompleteness, though there are some details which appear to the writer faulty. For instance, in the first year, forty lectures seem an entirely inadequate number to devote to the five natural sciences named. Would it not be much better to omit entirely the Mineralogy and Lithology, if no more time is at disposal? Again, the number of hours allotted for preparation appear to the writer too large in proportion to the number of lectures or recitations; it having been the experience at the institution with which he is connected that about two hours of preparation to one of recitation is about the maximum which give good results. These, however, are very minor details and call for no further discussion here.

In regard to drawing, it seems to me that the best results will be obtained by having the drawing in each department supervised by the teacher in that department, instead of by one professor of drawing. In fact, with a large school it is difficult to see how the latter plan is practicable. Each teacher should be enough of a specialist to be competent to look after the drawing connected with the subjects he teaches. In field-work, the class should be divided into sections so small that each man should be kept occupied all the time. This, with large classes, requires, of course, a number of instructors. Finally, I cannot fully agree with Professor Waddell that students should be required to spend very much time in making estimates of cost, or in becoming familiar with current prices. I think these are matters which are better left, in great part, for the student to learn after he graduates; and in ninety-nine cases out of a hundred he will have ample opportunity, before he is himself in a position to make a detailed estimate of cost, to see how it is to be made. In the work of designing, economy should, of course, be particularly dwelt upon, and in comparing different methods and projects it will frequently be necessary to refer to price lists or to engineering periodicals for market prices of ordinary materials. And it seems to me more advisable to spend the time in expanding and enlarging upon this side of the question than in actually calculating the cost of many structures.

By Prof. A. J. Du Bois.

Professor Waddell's paper contains so many goods things and raises so many questions that I can only briefly notice a few. The practical question with teachers is not so much what is the ideal course, as how best to approximate to such a course under special conditions and restrictions. Of these restrictions, lack of means is by far the most important, and will, I think, be found to be the direct or indirect cause of nearly all the exceptions and criticisms which are usually made as to methods of teaching and scope of instruction. The whole question thus narrows down in practice to how can one do the best with the means at command. Given so much teaching force, so much time and so much plant, how can so many students be best prepared? This is as much a question of skillful engineering as any likely to arise in the engineer's practice, and for its best solution in any special case a clear idea, apart from any limitations of what should be aimed at and of the general principles which should guide, are of the first importance. In this respect Professor Waddell's paper seems to me of much value and full of good suggestions by which I for one hope to profit. I think I see in it the evidence of the thorough teacher and of an experience quite exceptional in some respects.

The first requisite is of course money. Insufficiency of means implies lack of ability in teachers, inadequate teaching force and plant, and insufficient time given to the course. I need hardly dwell on these points. They account in themselves for nearly all the faults and shortcomings from which our courses suffer. They are not, however, of equal importance. A real teacher is "born and not made." At least, unless he brings to his work that enthusiasm and special fitness and tact essential in any calling to real success, he is out of place and not the most eminent professional ability or experience can make of him a good or even desirable teacher, no matter how accomplished as an engineer he may be.

This point has not usually, I think, been insisted upon as strongly as it deserves. If, with unlimited means, our schools could call to their aid the first professional talent in the country, it is an open question just how much would to-day be gained by the students. Not every one can teach even that which he has thoroughly mastered, and instances of eminent learning and brilliant talents all but wasted in the professor's chair have been frequent enough to enforce this point. I am free to assert that in this respect lack of means is not so responsible for results as many suppose, and that mediocre ability in those who fill the chairs in our technical institutions is not the most noticeable evil. The true teacher finds his place in this direction, as in all others, and neither insufficient salary nor cramped facilities can keep him out, although they may cripple his efforts. To the born teacher there are compensations not measured in money. His vocation is the noblest and his rewards are of the highest. He has found his home in our schools, he has "come to stay," and his work is going over the land and will speak for him.

Inadequate plant is a more important limitation, but in most of our well-appointed institutions I think it will be found that if the plant is not all that could be desired, yet with skillful management it suffices for good, if not for the best results. Increased means well administered would undoubtedly do much for us in both the preceding directions, but I would not put the main stress upon them.

If I wished to point out the weakest spot in all our institutions I should confine my remarks to inadequate teaching force and time. Here, I think, is the place for reform, here first I would apply the means I covet, and here I would look for the cause and the remedy of those faults in method, system, curriculum and what not, which lie so open to the captious, of which we are ourselves so well aware, and which we are all trying so hard, and, as some think, so vainly, to eliminate.

A teacher's capacity to teach is inversely as the numbers he has to instruct. A "born teacher," say, is doing good work with good facilities, along a well-proportioned course. Now, then, double the number of his pupils and other things do not remain the same. His facilities are now inadequate, his whole course thrown out of gear, his methods must perforce entirely change. He spreads out too thin. His personality will not go round. His character, individuality, and enthusiasm lose their inspiring power. The nice touch of mind on mind, which is more to the pupil even than the knowledge imparted—the educating power—is weakened, and then methods become perfunctory, "marks" and "discipline" the necessary adjuncts to "machine teaching," make their appearance and the inevitable sequence of "cuts" and "skinning" follows. Here is the crying evil, and its consequences are myriad, and run through the whole system, lowering the standard of admission, working back upon the preparatory schools and forward through the whole course to final examination and to graduation. The teaching force, first of all and above all, must be kept adequate to the number of students. As civil engineering breaks up with the growing requirements of the day, into specialty after specialty, the teaching force must keep abreast of the requirements of the times. No one man or two men will do, but many permanent chairs must be kept filled and co-operating.

The fact is, we have gone ahead too fast in this country and tried to build from the top down. Instead of a thorough preparatory school system as a basis for all our higher institutions, we have commenced with the higher institutions, and based them upon the shifting sand of private tuition, and irresponsible, unorganized, unsystematic, and disconnected "private schools," where a dozen boys are "prepared" at the same time for as many different institutions with as many different standards and requirements. Then, in our higher institutions themselves, we have handsome buildings and expensive dormitories, and extravagant exteriors, with very often meagre equipment, and nearly always insufficient teaching force. Too much for show, and too little for work. The first duty of a college is to teach—to lodge its students in palaces of brick and brown-stone is not of such immediately pressing importance.

Next in order I would put lack of time. Our students partaking of the spirit of the age are in a hurry also. They want to get out as soon as possible and go to work. Thus our courses are crowded and curtailed. Not until these two points are attended to, and remedied, can we even begin to discuss with profit such questions of detail as curriculum and methods of instruction. Indeed, I firmly believe that if these two points were remedied, there would in a short time be very substantial agreement, and little to criticise on all these minor points. The greater includes the less, and we would do well in our discussion of this whole question to aim steadily at the center. My plea is then, in brief, give us money. Money for more teachers, money for more time. Time and teachers—not increased salaries, we do not ask even for that, but only more of such as we already have—and more time to work in. Give us these for a few years, and it requires no great boldness to predict that methods of instruction will better keep pace with the strides of engineering practice. Beyond these, we ask, and should have, sufficient means to keep up the plant and facilities to full efficiency, and to be independent of numbers.

No institution should depend upon its tuition fees if it is to do its best work. Directors and teachers—even "born teachers"—are human, and thoroughness of instruction, rigor of examinations and sufficiency of salaries should not be dictated by temporary policy, or affected by popularity, nor should the successful working of an institution be gauged by its numbers, only. Those who recognize only "success" would do well to define what they mean by the word, and to keep its necessary conditions ever in mind if they wish justly to estimate the problem our teachers are working out. To run a large institution in the best way and in the most economical way, to keep and attract students and yet enforce the necessary discipline, to pay salaries and preserve a high standard, is a problem not to be solved by off-hand discussion.

In this respect of entire independence of tuition fees, and also in their system of mutual co-operation which allows a student to freely pass from one to another in pursuit of special excellences, as well as in the thorough system of preparatory schools on which they are based, would I copy the institutions of Germany—and in no others. In other respects we may, I think, learn from them what to avoid. We do not wish our professors, as in Germany, to give a course of instruction upon one topic, as if that one topic were the chief and only one of importance to all the students whatever their aims. The relation of the topics to one another, their proper subordination to the entire course the student wishes to take, and the perspective of the course itself, are thus lost. Our professors must combine their forces for the special end the student has in view, and work in concert to that end. Not, as abroad, teach the civil engineering student geology, for instance, as if their aim were to become specialists in that one subject alone, or mathematics, as if their aim in life was to master quaternions; but measure the courses to the requirements of the section they instruct. Again, we do not wish our students, as in Germany, to run wild at their own sweet will, without oversight, discipline, or pressure of any kind, and without the remotest personal contact with the men who should mould not their minds alone, but their disposition and character as well. Our system here has grown up naturally to suit our soil, and should continue to grow and develop in accordance with its environment, and not be transplanted by force from a strange soil and made to suit different requirements. We acknowledge in this country responsibility to parent as well as to student, and rightly feel to the fullest extent the importance to the student of guidance as well as of instruction. No one who has seen the facility and rapid and masterly ease with which a well-disposed, rather ill-trained American youth transplanted too young to the soil of a German university can make the "descent to Avernus," would wish to copy this feature of the "University" until at least we have the same sound basis of preparatory schools to rest upon.

Finally, we do not wish to imitate the lecture system of the German university. For finely prepared, earnest, and matured students, there is nothing more stimulating than the viva voce instruction of a master, fitted by learning, enthusiasm, and love for his subject, and by brilliant talents. True teaching of the very highest order is here. Enthusiasm begets its like, mind answers to mind, and lessons are learned which are not to be found in books. There is no one who has benefited by such instruction who would not wish to impart it if he could. But he is the wise teacher who recognizes its limitations and its requirements. Lack of co-ordination in the professors, "Academische Freiheit," and the "lecture system," pure and simple, are characteristics of the university abroad which we do not need to copy at home. A union of text-books, of recitations, and of lectures in proportions to be determined by the character of the class and the teacher's own ability, would seem the wisest and best method, and the necessity of some system of discipline which will brace up a flagging or indolent student under such a system is obvious. Hence the "marking system," which is the cause in unwise hands of so much evil, which is so easily liable to abuse, and yet which seems in some form so necessary. The best solution would seem to be that the student should not know nor care to know his "mark." It is simply the convenient method by which the teacher can grade the student's standing and work, and upon the basis of which he may decide as to the student's progress and his fitness to continue the course, or may give needed and timely warning to the parents. This much seems necessary, and more seems unadvisable. If grading by scholarship is necessary, that should not depend upon "marks" alone. But the existence of such marks will be no hindrance to the teacher in deciding.

Finally, the teacher, not overburdened by the size of his division, can come into and should earnestly seeks personal relations and personal contact, should encourage, criticise and warn, and learn the personal wants and individual character of the student. So far from antagonism, there should be warm and close relations, and the experience, I am confident, of every good teacher, is that nothing is so easy to gain as the confidence, good will, and hearty admiration of a well-disposed, ingenuous student, or more richly repays the little trouble required to get it. An *esprit de corps* is thus guaranteed which recognizes the teacher's difficulties, appreciates his labors and frowns down dishonest practices. Friendships are formed which endure beyond the class-room, and the most prized rewards of the teacher's vocation very often meet him from this direction. I speak from experience here, that which I do know, and to any teacher reading this who doubts the fact, I simply say, "try and see." Barren must the record of that teacher's life be which has nothing to tell of such rewards. The teacher whose work and responsibility end when he has heard his recitation and recorded his "marks" or delivered his lecture, is a man out of place, who knows not the true dignity of his vocation. I look back now on over ten years of work in the class-room, and dismal would be the retrospect and more dreary the prospect if my sole rewards were found in my salary and in perfunctory work alone. As it is, had I my life to live over and my choice again to make, in view of much that is drudgery and much that I might hope to achieve in other directions, in spite of low salary and much that is discouraging and disheartening, in spite of hampering limitations and the consequent dissatisfaction which must always attend the performance of work below one's ideal and best abilities, remembering the rewards which have come to me—rewards not measured in money value—and the many satisfactions of mutual help and kindliness with those I have guided—I could not but choose again the same path.

That the activities of the good teacher, not overburdened with numbers or class exercises, will not end with his class, goes without saying. It is impossible to meet fairly the inquiries of fresh young minds, to go over and over, with care and thoroughness, fundamental principles, and to try yearly to bring out with clearness their best and freshest applications, without one's own mind being stimulated and quickened to productive work. Still, these activities should, and I think generally do, lie more in the line of research and of inquiry rather than in the lines of practical operation. The teacher cannot pursue his vocation with one hand and put money in his purse with the other. No half-hearted allegiance should be tolerated. Let the active members of his profession erect their structures; his work lies in perfecting the science which those structures illustrate, and in sending out men familiar with its results.

As to the details of the curriculum, it must be borne in mind that engineering is both a science and an art. As a science, the school and teacher can do much to train the student in the comprehension, grasp, and use of its principles and laws. This should be as broad and full and thorough as the time and abilities of the teacher can make it. Nothing should be allowed to curtail this. The art, or methods of application, on the other hand, should, in the school, be subsidiary and illustrative—selected for their tonic effect and for the point they give to the training in the principles—so that these may be in no danger of losing vitality or becoming too abstract. Everywhere they should tie the student down to the fact that what he learns he must use, and in every case he must apply his principles thoroughly and in practical detail. But it is not necessary that such applications should be very numerous or multiplied, if only their scope be wide. The object is not skill in the doing—that will come in after life—but skill in the applying. A few well-chosen applications thoroughly done are better than myriads of detached applications repeated for the sake of mere manual facility. In field-work or designing, a single location well worked up and completed, a single design thoroughly executed, with every side issue and every question arising in the progress of the work followed up and settled, are better than many miles run and much paper spoiled. Slow, steady, intelligent, painstaking application of principles, everywhere searching the why and wherefore, should be the aim of these practical applications. The habit of thinking, of understanding, of applying knowledge recently acquired is the end sought, not rapid execution or showy results; and the student is thus taught by contact with practice how much must depend always upon himself, his intelligence and "common sense," how much there is which books and formulæ cannot include; in short, how true and vital is the saying attributed to one of our foremost engineers, that "it takes nine pounds of common sense to apply one pound of science."

Even though such applications should not perchance meet the requirements of the most recent field practice, or even be "antiquated," I venture to think that thus taught, the effect and result will be more valuable in after practice than a mere superficial practice of even the most approved modern method on a hasty scale. The habit of understanding and of thorough honest work will not fail a student in need, and even though he may never have heard of "grade plugs," nor be up in the latest method of keeping field notes, nor the shortest cuts in figuring earthwork, he can well stand the temporary embarrassment and yet come out finally and quickly well to the fore. Art is long, but sound principles, soundly applied and thoroughly mastered, are the best introduction to any handicraft.

With Professor Waddell I would draw the line in mathematics at the calculus. The engineer is required to use the mathematics and he should find in them a ready tool. But he is not expected to pursue the mathematics as a specialty nor to develop them as a science. If any problems in civil engineering call necessarily for any higher mathematics than the more simple applications of the integral calculus, I know of none. In the study of this subject applications and principles should go hand in hand. To lose sight of practical use and bearing is here very easy and very disastrous. Nowhere does the student stand more in danger of letting his reasoning powers lie dormant and relying upon memory, and the very facility of the instrument and its processes are apt to cause him to lose sight of the ideas, relations, and logic with which he is dealing.

Time must put an end to these hasty remarks. Professor Waddell has given us all much to think of, and in his paper are many hints and suggestions, the result of the experience of a thorough teacher dealing with an exceptionally fine class of students, which will not be without fruit.

To those in the active pursuit of their profession to whom the courses of instruction as existing in our technical schools may appear deficient, especially to those of this class who have themselves taken such courses, there may well seem much to criticise. No one can realize this more than those in charge of such instruction. Much may well have occurred to them even before the graduation of those now ready and qualified to point out such deficiencies. If such criticism go to the root and show the reason and point out the remedy, all engaged in the profession of teaching can only welcome and encourage it. In this spirit we join hands. But to all I would most earnestly say, search and see if most, if not all, of the serious shortcomings are not directly or indirectly due to lack of teaching force. If so, let us not lose sight of the cause in the symptoms. When we call to mind that the entire technical education of this great country rests almost wholly upon the free gifts of private munificence, we may well be proud of what has been accomplished, and have confidence in the future of a system unique in the history of the world. Let those who have built it up have due credit. The record of the administration of this great trust can only welcome investigation, and it justifies the belief that the result can only be an increase of that public confidence and intelligent generosity to which it owes its existence.

SOME NOTES
UPON
CIVIL ENGINEERING EDUCATION
WITH
SPECIAL APPLICATION TO JAPAN.

INTRODUCTORY NOTES.

"Some Notes Upon Civil Engineering Education, with Special Application to Japan," was written at the request of the Society for the Promotion of Engineering Education. Internal evidence makes it apparent that little time was available for its preparation, but, fragmentary as it is, the tersely expressed ideas it contains are very much to the point and eminently worthy of attention.

It is notable that the professor of engineering is nowadays duly esteemed for his ability as an engineer, probably more than as an instructor. He is frequently called into consultation where the questions to be decided are highly theoretical and scientific. It is true there are still engineers who look upon the professor as a visionary, but they are generally those men who do not possess a very deep knowledge of first principles, and, consequently, overestimate the value of practical experience. By virtue of the chair he occupies, the professor is generally held to be in a position particularly favorable to the rendition of an unbiased opinion upon scientific subjects, and he is in demand as an arbiter, especially in mechanical and electrical lines. This attitude of the public lends much to the attractiveness of the teaching branch of the profession, and in some measure compensates in honor for the lack of remuneration. It is true, however, that the true teacher finds his chief compensation in the work itself, in exerting a beneficial influence upon the student, in seeing him grow in knowledge and capacity, and in molding minds rather than matter.

In the light of the recent remarkable development of Japan, it is interesting to note the reasons for it advanced by Dr. Waddell and Professors Gray and Mendenhall. The remarkable aptitude and energy which characterize the Japanese student are in him accompanied by great pains and patience, whereas in the American they are generally assumed to relieve him of the need of hard labor and close attention to detail. The American is impatient to be getting on, while the Japanese has a passion for thoroughness. Probably the chief weaknesses of our recent engineering graduates are a lack of system in their work and a tendency to be superficial. They are often in possession of much half-grasped information and are not sure of their ground. The Notes which follow suggest some of the reasons and remedies for these conditions.

SOME NOTES UPON CIVIL ENGINEERING EDUCATION WITH SPECIAL APPLICATION TO JAPAN.

Much as the writer would like to prepare a paper upon "Engineering Education in Japan," which he was invited to do, lack of time has prevented his doing so. However, he is glad of the opportunity to make a short, informal address, by dictation to his stenographer, upon the general subject of Civil Engineering Education, a subject in which, perhaps some already know, he formerly took the deepest interest. More than that, he can say truthfully that there is still no subject, his own chosen specialty not excepted, in which he is more interested. It is, in his opinion, the most important branch of our profession, for the development of all other branches is dependent upon it.

Unfortunately, for many years the practicing members of the profession have had a tendency to look down upon and sneer at the professors of civil engineering. Such a tendency exists more or less to-day, but by no means to such an extent as it did ten or fifteen years ago. Undoubtedly, the formation of this Society * has had a great deal to do with the elevation of its specialty in the eyes of brother engineers; and there is reason for hope that in years to come it will succeed in placing the professors at the head instead of at the foot of the engineering profession. The time was when a man who could run a transit without making mistakes considered himself superior to nine out of ten of the professors of civil engineering. That he was entirely wrong goes without saying.

It is true that there has been a tendency among literary colleges, universities, and even some technical schools, to engage cheap men to fill the engineering chairs. Such action, of course, must keep down the general status of the specialty, but time and experience will assuredly correct this error. The average professor of civil engineering is generally insufficiently paid, and that fact alone militates greatly against the high standing which professors of civil engineering ought to take in the community. Compared with those employed in other branches of the profession, teachers of civil engineering are paid but little more than half what they ought to receive. This is probably because the professor's work is to a large extent a labor of love. One cannot, of course, object to such devotion to the interest of truth and investigation; nevertheless, "The laborer is worthy of his hire," and the engineering teacher will never be fully appreciated until he is properly paid.

Some ten years ago, "Engineering News" published a paper by the present writer, entitled "Civil Engineering Education," in which was

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* Society for the Promotion of Engineering Education.

outlined what was considered to be an ideal course in civil engineering. It has been a matter of great satisfaction to note from time to time that the developments in teaching civil engineering have been directly in the line thus indicated. The writer has for some time thought of suggesting to the Programme Committee of this Society a condensation of this old paper and making from it a new one to present to the Society for further discussion, together with a few ideas picked up in the last ten years of active practice. His opinion of what a course in civil engineering should be is briefly as follows:

First—No really thorough course in civil engineering can be given in less than five years.

Second—Every student, before admission, should have had a thorough course in non-technical subjects, the broader the better. More especially should he be well drilled in his own language and literature, for in a technical course but little time is given to anything outside of the regular routine of mathematics and technics.

Third—The technical course ought to include a great many branches allied directly and indirectly to civil engineering, such as electrical, mechanical, and mining engineering; *i. e.*, the course should give the rudiments, at least, of all these subjects; and, in addition, such subjects as Geology, Chemistry, Physics, Lithology, and Mineralogy, should be taught, at least in an elementary manner, but so well that the student will really know something about them when he completes the course.

Fourth—The amount of work now required by the best technical schools of this country in the so-called theoretical courses, such as pure mathematics, rational mechanics, and descriptive geometry, should be increased rather than diminished.

Fifth—Graphics in all its branches should be taught much more thoroughly than is the rule in America; although perhaps not so much time should be devoted to it as is customary in European technical schools. If the student be taught to reason graphically, he will, in practice, be enabled to eliminate a large amount of drudgery from his computations.

Sixth—Every student at the beginning of the course ought to be made proficient in the use of the slide rule.

Seventh—All purely technical courses should be made much more extensive than is usual, and in each course the student should be required to make a complete design, with an estimate of cost, for some structure or construction. This design should be made under the eyes of the instructor. There is a great deal of humbug in graduating theses. Very often a student goes up to his final examination with a thesis prepared by somebody else. A single thesis in a four or five years' course is not enough, for there should be a thesis in each branch of practical engineering work, including, when practicable, surveys and other field work.

Eighth—Classes in engineering should not be too large. In the writer's opinion, an instructor cannot teach properly more than twenty men at a time, and a much smaller number would be better. This is because, to give the student the full benefit of the course, the professor should take a personal interest in all that the student does, and should be his friend, rather than, as is too often supposed, his enemy, whose sole object is to condition him and drop him from the course.

Concerning these two methods of teaching the writer can speak from experience, for he has tried both. At the Rensselaer Polytechnic Institute, where he both studied and taught, the course used to be made unnecessarily severe, graduation from that institution being an extreme example of the "survival of the fittest." In the writer's class only twenty-four men out of sixty-six graduated, and in the class before his only eleven graduated out of a like number. Surely the dropping of five students out of every six indicated unnecessary severity. Of course, such a method of instruction makes a great reputation for the institution, but it does not do the best possible thing for the student, who is paying a good price for his technical education. Many a good man who has been dropped from the Rensselaer Polytechnic Institute could, with a little help and encouragement from his professors, have taken his diploma and done credit later to his *alma mater*. In making such statements as these, there is no purpose of suggesting the lowering of the standard for graduation. On the contrary, it should be higher than ever, but, instead of throwing unnecessary obstacles in the way of the student, he should be aided in every legitimate manner to get through his course creditably to himself and to the institution. Again, regarding the course at the Rensselaer Polytechnic Institute, it should be understood that it is referred to as it was some twenty years ago and not as it is to-day.

And now a few words upon the subject which was suggested, viz.: "Engineering Education in Japan."

Early in 1882 the writer was appointed to the Chair of Civil Engineering in the Imperial University of Tokyo, and started work in September of that year. The subjects in the department were those pertaining to civil engineering proper; that is, all allied subjects were taught by other professors, including pure mathematics and rational mechanics. This special department covered everything of a practical nature, such as surveying in all its branches; railroading; hydraulics, including waterworks, harbors, rivers, and canals; hydraulic motors; arches; resistance of materials; roofs; bridges, including both sub-structure and super-structure; and sanitary engineering.

At the outset a trial was made of the Rensselaer Polytechnic Institute tactics, by subjecting each student to rigid examination every day, but it was soon found that this was unnecessary, and gradually the methods were changed, until after a while there was no trace left of the old ones. Eventually the courses were given by laying out at the beginning of each a certain amount of reading to be done in a given time, and letting the students set for themselves each day the amount of ground they desired to cover. At the hour for recitation the professor met the students and acted in reality as consulting engineer for the class, answering questions and asking others in such a way as to bring out all the more subtle points of the subject. In this manner about three times as much ground was covered in a given period as was formerly covered at Rensselaer.

Some one may remark that the course could not have been so thoroughly given, and that the students could not possibly remember as much as they would, had the course been shorter and the drill more thorough. In reply to such an observation it should be stated that no reviews were ever given, and that the examinations covered the entire ground of the course without any set topics. The students were expected not only to answer all practical questions which might be asked, but had to give mathematical demonstrations wherever such were included in the technical books that they had studied. On a number of occasions it was necessary to mark examination papers one hundred per cent.; for they were absolutely without flaw, unless one were so captious as to criticise an occasional awkwardness in the English.

The success thus met with in teaching in Japan must be attributed to a great extent to the wonderful capacity of the Japanese student to imbibe ideas.

The students were the writer's friends, and are so yet. Most of them still write to him once or twice a year; whenever there is any information of a technical nature that they cannot obtain in their country they apply to him for it; and it is invariably obtained for them. There is no professional success which the writer has achieved that yields more satisfaction than this does; consequently it is easy to see why he is in such sympathy with the labors of this Society and to understand the reasons for the statement made at the outset of his address, viz., that there is no higher branch of civil engineering than the specialty of technical education.

DISCUSSION.

Professor T. C. Mendenhall said that he could add but very little to the interesting paper that Professor Waddell had presented. It was perhaps but justice to say that what one can accomplish by a given method with a given set of students to deal with is by no means an index of what one can accomplish by the same method with an entirely different set of students to deal with. No one appreciates that, probably, more than Professor Waddell, yet he has perhaps intimated in this paper that he considers the methods that he pursued there very decidedly superior to any that he was accustomed to use at home. The fact is, as probably everyone knows who has had to do with the instruction of Japanese students, that there are many conditions existing among them that are rarely found to exist among students in this country or probably in any European country. The speaker felt sure that Professor Gray, who was also his colleague in Japan at the same time, shortly before Professor Waddell was there, would agree to that. It is not safe, therefore, to decide that a method which fits those people is altogether the best for the young men here, the circumstances are so very different. Students in Japan are very remarkable. In the first place, they come—they did come, and no doubt it is still the case—they come with a hunger for learning and with an anxiety to make progress and to grow and grasp and master everything which is within their reach, that is not equalled in other countries, and of course that has a good deal to do with the fact that Professor Waddell could be the consulting engineer of the class and the fact that they could make most rapid progress under such conditions. The author might find it impossible to make such progress in this country with a set of American students. In other words, while agreeing with him in every respect in regard to his statement as to Japanese education and Japanese students, the speaker thought that if Professor Waddell had, since coming from Japan, taught some classes of American young men as some of the rest of us have done, he would probably still adhere to the more conservative methods.

Professor Thomas Gray said that he had very great pleasure in teaching Japanese students engineering for several years. He agreed perfectly with Dr. Mendenhall in his remarks with regard to the difference between a class of Japanese students and the classes in this country or the classes to be found in other countries. The Japanese student is especially attentive to the instruction given him, and there is never any question of discipline coming up in the Japanese class. The remark which Professor Waddell made in regard to some papers being marked a hundred because they were absolutely flawless, was a common experience. The speaker had found it necessary to mark many papers a hundred because the answers were given in precisely the same words which had been used when the subject was explained to the class. He was not quite sure how that was to be accounted for. He had been inclined to think, as the Japanese really committed so much to memory from childhood up, that it was no trouble for them to reproduce almost anything you told them. It is certainly very remarkable, the way in which they can absorb what is told them and reproduce it in almost exactly the same form in which they got it. The courses of study which are carried out in the colleges in which he was teaching were very similar to those which are carried out in Europe. The methods of teaching were also similar. He could say also that not only was the method which Mr. Waddell tried successful, but other methods were also perfectly successful. All produced excellent results in teaching in Japan, both lecture and recitation methods. It did not seem to matter much how one taught, providing the whole of the important part of the subject was covered excellent results would be secured in that country.

A LETTER

RELATING TO

CIVIL ENGINEERING EDUCATION.

INTRODUCTORY NOTES.

The letter or paper following was written so recently that it must of necessity contain the results of its author's latest thought and experience. In the course of his professional work he has employed a large number of young engineers, many of them fresh from school, and their deficiencies and the peculiarities of their education have presented excellent opportunities for the study of the courses and methods of instruction obtaining in the schools from which they were graduated. He has also delivered many informal lectures to the undergraduates of various schools throughout this country and thus has had wide opportunities to see the work of instruction in progress. Consequently, though eighteen years have elapsed since Dr. Waddell was actively engaged in teaching, he has constantly remained in touch with the work, and this letter is more pointed, cogent, and mature, within its scope, than anything he has previously written on the subject. The years of actual practice have lent the perspective and given a clearer, sounder view of the various courses and methods of instruction than actual participation in the work could have afforded. Though the subject is only touched, and a great many important matters are left entirely unconsidered, the plans outlined would, if followed, effect a great improvement in the course of many an engineering school.

The suggestion that the student spend a portion of his summer vacations on some engineering work is excellent but hard to follow. It is substantially impossible for the student to obtain pay for such services as he can render, for his instruction costs more than the value of his unskilled labor. Consequently, few students apply for such work and fewer still obtain it. The faculties either disapprove of vacation work or take small interest in the matter, for they rarely assist the student who seeks such opportunities. Yet the advantages which would accrue from a month's or six weeks' work each summer can hardly be over-estimated. It would provide application of the principles already learned, greatly increase interest in the studies still to be pursued, bring the student into contact with those who would be of service to him in his professional work, teach him method, bring him a glimpse of business, and generally provide him with a position upon graduation. The last benefit alone would compensate for the expense and labor, for the new graduate rarely finds it an easy matter to obtain his first position. His total lack of experience makes him undesirable except for work closely approaching manual or clerical labor in character. Every student whose health and purse permit should undoubtedly spend the better portion of his summer vacations in engineering or shop-work, even if he is obliged to perform clerical or manual labor. No portion of his four or five years' course will be more profitably spent.

In order to assist the students to obtain summer employment and to keep closely in touch with the advancement of engineering practice, each technical member of the faculty should maintain the closest possible relations with practicing engineers, manufacturers, and contractors. New methods of design, manufacture, and construction often remain unmentioned in the technical press long after they are proved advantageous, but the instructor should be early in position to obtain and use information relating to them. He should teach the practice of to-day, not of one or two or ten years since.

In relation to the conduct of the classroom and laboratory work, the instructor is in better position to judge than the practicing engineer, but the latter is better able to judge what goes to make success in the work-a-day world of which he is a part, and, as it is the purpose of the school to graduate successful engineers, it is certainly incumbent upon the members of the faculty to keep in close touch with the practitioner and make full use of the advice and aid he can give to this end.

A LETTER RELATING TO CIVIL ENGINEERING EDUCATION.

KANSAS CITY, MO., May 23, 1903.

MY DEAR SIR:

According to the promise, made several days ago, I shall write to-day my opinions concerning various matters in relation to civil engineering education. It will be necessary for me to make my remarks general, because I am not well enough acquainted with the course in engineering given in your institution to warrant my passing an opinion upon it, but this much I may say—knowing as I did the general character of the work done there twelve or fifteen years ago, and not having heard that any changes had since been made—I was most agreeably surprised to note the progress that has been effected and the great enthusiasm of both professors and students in everything relating to the course. It was evident to me that the engineering department was preparing to do some most thorough work; hence I should not be surprised if within the next five years your course in engineering were recognized very generally as one of the best in America. A great deal, of course, is contingent upon the amount of money you have to spend; but much more depends upon how earnestly both the professors and the students work to accomplish the purpose in view.

If the following suggestions aid materially in the development of your engineering department, I shall be deeply gratified. Please understand that any observations of mine which are of a critical nature apply to engineering education in general, and not to the particular course given in any one institution.

In my opinion, no engineering course given anywhere approaches at all closely an ideal one, such, for instance, as that described at length in the paper I wrote in 1886, and which was published by "Engineering News" in January, 1887, with numerous subsequent discussions. It is true that all the development in civil engineering education which has taken place since that date has been directly along the lines then laid down, still there remains much to be accomplished before the ideal, or anything approaching it closely, is attained. While it is undoubtedly true that there is no technical course given to-day which is sufficiently free from restrictions to permit its development into an ideal course, that is no reason why the professors in any technical school should not strive in every way to approach the ideal; for in so doing they would certainly benefit the school greatly and provide the students with a more thorough training.

My first proposition is that an ideal course in civil engineering cannot be given in four years, and that not even five years would suffice, unless the requirements for entrance were made pretty high. Granting that the course be limited to four years, the question arises how to use this time to the greatest advantage, and how to crowd into it the maximum amount of properly given instruction. The following are the methods that I would suggest:

First—Raise the entrance requirements as high as possible without depleting the freshman classes too much.

Second—Reduce the duration of the several vacations to a minimum.

Third—Throw practically all the field-work into the vacations.

Fourth—Omit all courses that are unnecessary for an engineer, and reduce all comparatively unimportant courses to the shortest period advisable.

Fifth—Utilize to the best advantage all the possible working hours of the entire four years.

By adopting these five expedients the actual working time of most engineering courses could be increased by from fifty to one hundred per cent.

I shall now discuss these expedients in the order stated:

First—Raising the requirements for entrance can be carried advantageously to a certain point only, even where the number of applications for admission is unlimited; because there are certain courses, notably those in pure mathematics, physics, and chemistry, that are not taught properly outside of a technical school. It may be practicable to demand for entrance the entire subjects in algebra and geometry; but usually it is better to teach the higher portions of these in the technical schools. It would be unwise to require for entrance trigonometry, analytical geometry, or calculus.

If there could be established, either within the institution or closely allied to it, a preparatory department, the entrance requirements could be raised as high as desired, because you could then control the character of instruction given in the preparatory course.

Second—In my opinion, the vacations in technical schools, universities, and colleges are altogether too long. The grand total per annum generally amounts to about four months, and in some institutions to still more. Two months all told ought to be sufficient, especially if that time be properly distributed; but, as it might be difficult to make such a radical change as this would involve, you might compromise on two months of summer vacation and three weeks more distributed throughout the rest of the year, say one week at a time. I have always felt that three consecutive months of idleness are detrimental to a young fellow at school or college; for then he is liable to get into lazy habits and out of practice in applying himself mentally. I believe that a radical change of work, rather than its entire cessation, is a better method of obtaining recuperation and rest. Yet, I think a few weeks in summer spent in the woods or on the waters, free from all care, are an excellent tonic, both physical and mental.

Third—By throwing all the field-work into the summer vacations the boys would have a change of work that would give them an excellent rest, and would be benefited physically. All three of the summer vacations might be spent by the students in this way, or perhaps portions of them could be utilized by securing practical experience in office or field in the employ of practicing engineers or contractors. The faculty should arrange several months before the summer vacation begins the way in which each student is to spend the time; and they should make it their business to obtain temporary positions in office or field for those of their students who are not going to work on the regular surveys. If in the future I can aid your faculty in finding such positions, I shall be pleased to do so to the best of my ability. Provided that the student does not expect compensation for his untrained services, and that he will work just as faithfully as the paid employees, there ought to be no serious difficulty in obtaining as many of these temporary positions as may be desired.

Fourth—In most technical curricula there are some courses that are really unnecessary; for instance, foreign languages. These should be omitted entirely. Again, more attention is sometimes paid to certain courses than their importance warrants; for instance, botany. These should be cut down to the extent of leaving in only those portions that bear directly on the general engineering course or that are likely to prove useful in the young man's career after graduation.

Fifth—The members of the faculty, by working together in perfect harmony, could save for recitations and lectures many hours that are too often wasted by the clashing of class-work. A little forethought and the application of the principle of "give-and-take" would arrange matters so that there would be no lost or deferred recitations or lectures. These remarks apply especially to occasions when lectures are given by engineers who are not members of the faculty, and whose time, being valuable, must be utilized as much as possible during their stay at the institution, even if doing so interferes seriously with the work of the instructors.

It has always seemed to me that a whole holiday on Saturday is a waste of the student's time, and that a half holiday ought to be ample. A cessation of all school work from Friday afternoon till Monday morning causes too great an hiatus in the student's working life, rendering him, so to speak, unstrung. It seems to me that a student, like a piano, needs to be keyed up constantly to a certain pitch, in capacity both for work and for enthusiasm.

In many institutions the students merely recite for two or three hours per day, and the rest of the time is their own to do with as they will. This appears to me to be wrong, for I think that from nine o'clock till noon, and from one o'clock till four, or in some cases later, the students should be in the buildings of the institution, working to a certain extent under the professor's eye. In this way they come more under the personal influence of the faculty, and gain correspondingly. The personal influence of the instructor has a great effect upon a student for many years after graduation; and the more earnest and interested the professor is in the student's welfare and advancement, the longer after graduation will his influence endure.

Now I must pass to other and more specific considerations. To begin with, I shall treat of the various methods of giving instruction, viz., by lectures, by text-books, by books of reference, by recitations, by examinations, and by class-room practice.

In some schools the lecture system is carried to an extreme, whole courses being given by it, and the students being required to copy lecture notes without end. Such a method of instruction is most lamentably defective. Lectures are admissible only in three cases; first, at the beginning of a course, in order to outline its extent and to make the students acquainted, in a general way, with the subject they are going to study; second, at the end of a course as a résumé of what they have learned, and to impress upon their minds its most important features; and, third, for those courses in which the matter to be treated is not covered in any book. In the last case the lecture system of instruction should be followed only until the instructor has been able to reduce his lecture notes to book form.

Forcing students to copy lecture notes is an imposition—more than that—I look upon it as a species of dishonesty on the part of the instructor, in that he is either too indolent to do the writing himself or too penurious to have it done by a paid assistant and manifolded for the students' use. Every minute spent by a student in copying notes is a minute lost from his life—it is absolutely wasted. When he is copying notes he can think of nothing but the mere mechanical act; and if perchance his thoughts stray for an instant to something more entertaining, he is liable to make a mistake that may give him hours of annoyance afterwards. No notes copied by a student are sufficiently accurate to use in place of a text-book. Of this I speak from experience, based, however, mainly on observation, for never once during the six years I spent in teaching engineering was I guilty of forcing my students to copy notes, and I had but little of this work to do during my student life at the Rensselaer Polytechnic Institute. When lecturing on professional matters I never want any of my hearers to put pencil to paper. They cannot listen properly to me and take notes at the same time.

The method of teaching by text-books is by far the best and most satisfactory; but it should not be adopted exclusively, for fear that the students will degenerate into mere book-worms.

The method of instruction by daily recitations with set lessons is undoubtedly the best, but it can be carried to extremes, with the result of making the young men feel that they are being treated like school-boys instead of like engineering students. The set lessons are all very well in their way, but they should always be supplemented by a course of reading in the reference books; and the professor should lay out in advance what is to be read in each book, letting the students take their own time for it, provided, of course, that they cover the entire ground before the course is finished.

This use of books of reference makes the instructor, in a way, the consulting engineer for the class; and he should always encourage his students to ask sound, sensible questions concerning everything treated. If the boys be not in earnest, or if they be of the "shirker" type, they are likely to abuse this privilege by asking numerous questions of the instructor so as to prevent his interrogating them on their daily lessons. Any tendency of this kind should be "nipped in the bud," and the offender should be made to comprehend that his little game is understood.

Books of reference should be used very freely in every course—in fact, the class should have at hand a sufficient number of copies of every technical work of any value that treats of the subject considered. If the students are poor, the institution ought to lend them these reference books from its library; but if not, the boys should be encouraged to purchase them for their own professional libraries. I believe that every student who has the means should start while at school to collect, under the direction of the professors, a good professional library. The young engineer will need these books when he begins his practical work; and if he is then somewhat familiar with their contents, as he would naturally be from having had them at hand during his technical course, so much the better for his professional advancement. Each student should spend in this way fully one hundred dollars a year, if he can afford to do so, and even more if he be well provided with funds.

The final examinations, which, I think, should always be both written and oral, ought to cover not only the text-book work but also the general reading; most of the questions on the latter, however, should be oral.

Whether a student is to be passed or conditioned in any course should not depend solely upon an average of his marks, but due consideration should be given to his work in both the recitations and the final examination, allowing properly for the faithfulness and the personal peculiarities of the man. The professor's opinion of the working value of his accumulated knowledge should be the principal factor in the determination.

I am a firm believer in having the students do the greater part of their studying under the eye of the professor, who can then see how each man applies himself and that he does not waste his time. All drafting should be done in the class-room. When the students are permitted to do some or all of it at home some of them are tempted to get others to do the work for them.

When a professor has his students study in his own room, he will be able to teach many of them the way to apply themselves and, in fact, how to think. Most students who fail do so from lack of willingness or ability to concentrate their mental powers. I believe it is possible for an instructor who takes a true and deep interest in his students and in their success to teach the laggards to think. I have often tried it successfully by occasionally studying out a difficult point aloud, and indicating to the boys the course of reasoning that it was necessary to pursue in order to comprehend the subject and to solve the problem. They should be taught that it is essential to understand every point thoroughly, and that they must never be content with a partial comprehension.

Lectures two or three times a month by practicing engineers on practical subjects would be an excellent thing for the students, not only because of the valuable hints that they would thus receive, and which their professors, owing to lack of actual experience, could not well give them, but also because becoming personally acquainted with these lecturers brings the young men in touch with the outside world and teaches them something of the practical application of what they are learning. While it is, of course, a good thing to choose these lecturers from the prominent engineers of the country, it would be a mistake to rely wholly upon them, because you would not be able to secure enough of them. First-rate, practical lectures that will appeal strongly to the students could be given by young engineers who have been only three or four years in practice; and your own alumni would, as a rule, be the best of these to choose. Young engineers, having come so recently from the technical schools, would often know better than older and more experienced men just what information the boys need to help them out of their difficulties, and what is most likely to interest them. It would not be a difficult matter to lay out for several months ahead such a course of lectures on practical subjects; and in doing so I should be glad to assist you, if you so desire. I believe that I could secure for you for next year six or eight experienced engineers to give your boys some interesting and instructive lectures in various lines of engineering work.

It is a very poor plan to try to instruct students in practical subjects by providing them with professors who are not practical and who have had no actual experience in the special lines they are called upon to teach. Very often assistants to professors are chosen from the graduating class. No greater mistake than this could be made; for, in the first place, they cannot possibly know enough to teach, and, in the second place, the students are not likely to have the proper respect for instructors with whom they have been so closely allied in the intimate relations attendant on student life.

Don't overwork your professors, but avoid reducing them to mere teaching machines. A certain number of hours per day should be demanded from them, and the rest of their time should be their own for research, practice, or study. It would be well to lay out the curriculum so that each instructor would have occasionally a week or two of absolute freedom, in order that he may visit other institutions of learning, to see how they are doing work similar in character to that on which he is employed. He should have time to inspect large engineering works that are in progress, or manufactories and plants of various kinds, and to attend to some outside practice. If an instructor shows a tendency to neglect his regular duties for such outside work, he should be given a warning, and if he does not heed this, he should be replaced; for, while a certain amount of outside practice is good for both the professor and his students, too much of it is very detrimental to the institution. It does not do to work instructors too continuously, as they need more rest than do the students, not only because they are older but also because the strain from teaching is far greater than that from learning. An overworked professor cannot give satisfactory instruction, because it is impossible for him to arouse enthusiasm in his class when he himself feels hypped; and unless the boys are enthusiastic he cannot get the greatest possible amount of work out of them. It is my firm conviction that students who are taught to love their work will accomplish more than twice as much as students who are driven to it simply by the desire to pass. Such, at least, has always been my experience when teaching engineering.

Let me call attention to the remarks I made in a late address concerning the importance of all the "descriptive geometry" subjects. I cannot impress upon you too earnestly the necessity for all young engineers being thoroughly drilled in the principles and practical application of the various descriptive courses, including plane problems, projections, descriptive geometry, shades and shadows, perspective, and stereotomy. Besides their usefulness in designing, the mental training that one receives in their study is beyond estimation.

Nearly all the curricula of American technical schools are weak in the lack of a thorough course in graphics. Much more attention is paid to this subject in the French, Swiss, and German schools than is devoted to it in this country. An engineer who is trained to compute, estimate, illustrate, and even think graphically has a decided advantage over one whose education in this particular has been neglected. The study of graphics by proper methods teaches one order and systematization; and no prettier study can well be imagined. We need in English a thoroughly scientific, practical, and exhaustive treatise on the subject of graphics to use as a text-book in technical schools.

In my opinion, all engineering students should receive instruction in the principles and practice of architecture. The course given need not be very elaborate, but the instruction in the æsthetic features should be most thorough. If there is one thing in which American engineers are glaringly deficient, it is in the æsthetics of designing; and some of our most prominent engineers are the greatest offenders.

At the risk of rendering myself tiresome, I desire to emphasize all that I have said of late on the subject of making technical students true masters of the English language. Not more than one or two per cent. of the graduates of technical schools have been thoroughly trained in English; and there is nothing more important for a professional career than a sound working-knowledge of one's own tongue. In dictating daily correspondence, composing reports, preparing technical papers, writing engineering books, and in business conversations concerning large enterprises, the man who has a thorough command of his own language is far more likely to succeed than one who has not. There should be a long course in the freshman year devoted especially to the study of sound, practical English. In giving it, a variety of text-books should be employed; and the books of reference used should relate to engineering work, if there be such a thing as a really well-written, technical book. In this course students should be taught both to compose and to criticise, and all the class-work done should be made interesting. Ample time should be allowed for the course, so that when it is finished each student in the class will be able to read, write, speak, and dictate correctly and with comparative ease.

Be careful to confine the instruction to practical lines, avoiding all reference to antiquated language, poetry, and unusual or abnormal styles of composition.

As I would have all the students throughout the entire four years' course devote considerable time to the preparation of theses, reports, specifications, and contracts, I would let it be one of the duties of the professor of English to read and criticise all such papers and return them to the writers for either correction or rewriting.

The institution should be provided with several typewriting instruments, and several stenographers should be employed to take shorthand notes from the students' dictation. When not thus employed they could attend to the regular business correspondence of the faculty.

If any student desire to learn to use a typewriter, he should be encouraged to do so, but, in view of the short working time allowed for the curriculum, it does not seem advisable to give regular instruction in this.

All students should be taught to be neat, systematic, and accurate in all of their work; and any papers that fail to come up to a certain standard in these particulars should be rejected, and their writers should be compelled to do the work anew.

Accuracy in all calculations should always be insisted upon; and the students should be taught to what extent it ought to be carried in the different kinds of computations.

There should be a good, sound course in political economy and allied subjects; for an engineer ought to be a broad-minded man, while the training that he receives both in the technical school and after graduation tends to render him the contrary.

Engineering students should be given an elementary but eminently practical course in geology, and should be taught to recognize at a glance the ordinary kinds of rock that one meets with in engineering practice.

Instruction should be given concerning the various properties of the different kinds of timber, and the students should be taught how to recognize the various kinds of wood both when growing and after being cut, and how to distinguish between good and bad timber. The professor should avoid the danger of making them over-particular in their inspection by calling attention to the fact that absolutely perfect timber is not procurable these days, and by showing what imperfections are serious and what are not.

A thorough course should be given in the testing and the use of cement, with a descriptive treatment of its manufacture and composition; and in connection with this should be taught the proper manufacture of concrete, both by hand and by machine. Reinforced concrete construction should also be investigated.

Masonry, too, should receive due attention, and the students should be made familiar with the terms used therein and with all methods of quarrying and laying stone.

But I am now getting too deeply into detail, consequently I shall enumerate no more of the special courses required for an ideal engineering curriculum; but shall confine myself more to generalities.

There is one point that I desire to emphasize, viz., that the practical application and usefulness of every course that is given and of all parts of each course should be made clear to the students, not only in order to interest them in their studies, but also to enable them later to make use of the knowledge they acquire.

After each of the courses in the principal lines of engineering construction is completed, each student should be required to prepare a thesis on it, and these theses should include the designing, estimating, drafting, specifications, and contracts that would be involved in actual practice. This is probably the most important feature in an ideal engineering course, but it is one that has never yet been developed in any technical school to the extent that is advisable and attainable. The principal courses that I would suggest covering in this way are bridge superstructures, bridge sub-structures, dams and other constructions in masonry and earth, waterworks, sewerage, river improvements, hydraulic motors, steam engines, steel buildings and roofs, harbors, and docks. There are other constructions that might advantageously be added to the list, and there are probably some of those enumerated that would have to be omitted for want of time. In the production of these theses, practical instruction should be given in preparing all the reports, descriptions, specifications, contracts, and similar papers that would naturally be involved in actual practice on such work.

It would be an excellent plan to retain specialists of established reputation to give either entirely or partially the higher courses in designing. Such men might be induced to take a few consecutive weeks from their regular occupations in order to devote them to giving practical instruction to engineering students. However, their time would have to be paid for pretty handsomely; hence in the case of many institutions this method is perhaps out of the question at present.

I intended to cover in this letter my ideas of how the practical instruction in both class-room and field should be given; but I must desist, because this communication has already reached an unduly great length. However, as I have many peculiar ideas of my own in regard to how such instruction should be imparted, especially in bridge work, railroading, surveying, and hydraulics, I shall reserve these subjects with a number of others to converse about when next I have the pleasure of meeting you.

Please note that in this letter I have by no means tried to cover the entire ground of engineering education, and that for want of time and space, I have intentionally omitted many important matters; hence what I have written must be considered desultory and merely suggestive. To write a full report on such a broad and important subject as civil engineering education would demand weeks instead of days of deep thought and considerable investigation. The subject is one in which I take the deepest interest; in fact, some of my brother engineers term it a "fad" of mine. This may be true; but if so, it is a very important fad and one that is worthy of receiving all the attention that a practicing engineer can spare from his regular work. In fact, I consider engineering education the most important branch of the engineering profession, in that the development of the profession depends upon it more than upon any other branch; and I have no patience with those engineers who strive to place the professors of engineering upon a lower professional plane than the engineers who are engaged in actual practice.

To summarize and to present in a few words my idea of what engineering education should be, I would state that a highly educated civil engineer, in addition usually to being a specialist, must have a broad, general knowledge of all branches of the profession; that life is too short for a man to become acquainted with all branches during his early practice; and that the only way for him to become posted in all lines of work is to receive sound, practical instruction in them at his technical school, either before graduation or directly afterwards in a post-graduate course.

In conclusion, I might suggest that you could make a start on the incorporation into your course of some of these practical ideas by inaugurating a post-graduate department, and by giving in it most of the designing and estimating, and the preparation of specifications, contracts, and reports that I advocate.

Again, if you intend to try to make your institution recognized as eminent in the line of engineering, I would suggest that you would facilitate such a consummation by adopting the policy of including a few engineers in your governing board.

Very respectfully yours,

J. A. L. WADDELL.

COMMENT

Upon "Civil Engineering Education," "Some Notes upon Civil Engineering Education with Special Application to Japan," and "A Letter Relating to Civil Engineering Education."

There are three general classes of schools which offer courses in civil engineering. One is composed of weak institutions which endeavor to appear broad by offering perfunctory courses and professional degrees. Their equipment is commonly very limited and their faculty small, ill paid, and ill prepared. They obtain students because they are conveniently situated, because the cost of pursuing their courses is small, and because the student or those responsible for him are ill informed. A very small number of the graduates of such institutions succeed in their profession unless the defects in their education are remedied later at some better school. These institutions are in some measure fraudulent, for, like the correspondence schools, they make promises which are not fulfilled and turn out students who have an exaggerated idea of the extent of their equipment. Fortunately, the better schools are growing rapidly in number and fame and are crowding out these weak ones.

The schools which devote themselves entirely to technical work are of two grades. Those of the lower grade correspond to the technical high schools of Europe, and prepare men in the more elementary branches of engineering only. Their courses in mathematics are commonly very good, as are also the drafting and shop work and other courses which fit the student to earn his livelihood at once, but the courses are short and the requirements for matriculation are low, consequently their graduates are not prepared for the higher grades of professional work.

The second class of technical schools offer courses of the highest grade, and their graduates are prominently identified with the highest professional work. Their courses are what they purport to be, engineering courses, and nothing more. The amount of work they offer in the languages is the least which will enable the student to read the technical literature of other countries, and is offered for that purpose. History, economics, literature, the humanities, and the pure sciences, other than those upon which the engineering courses are based, the studies which make for breadth and culture only, are crowded entirely out of consideration by the purely professional work. Their graduates often lack breadth, in consequence, but the intensity developed by unqualified devotion to a single purpose often constitutes full compensation.

The third and largest class of institutions is made up of the universities, of which a school of engineering forms an integral part. In some instances the technical schools are predominant, in some of the older institutions the schools of liberal arts and of the older professions continue superior to the technical schools, but in the great majority of cases the school of engineering is co-ordinate with the others. The better universities offer courses and possess facilities for technical instruction which are equal to those of the best technical schools. They offer many other advantages which tend to broaden the student's education; for instance, the stronger man, who finds himself able to do more work than the engineering course provides, may take a few subjects in the other schools, such as the law of contracts, advanced English composition, economic geology, higher French and German, political economy, logic, or higher work in chemistry, geology, and mineralogy than the engineering course provides. But, in any event, the larger life of the university, the intercourse with students of very diverse interests, lends better perspective and does much to broaden the view, and to prevent the idea that his is the only important line of work.

The graduate schools of the universities are beginning to offer graduate courses in the various branches of engineering, and it appears probable that graduate courses of a high grade will be a prominent feature of the better institutions in the not very distant future. As the engineering profession grows older and more crowded, it will become more and more essential for those who will compel success to spend more time in making a thorough preparation. The number of students who pursue a collegiate course before taking up their engineering studies is gradually increasing, and it seems not improbable that in time the course will be modified to meet the demands of students of this class.

The requirements for entrance to engineering schools have been much discussed by the Society for the Promotion of Engineering Education and, in consequence, they are now very uniform. From year to year they are being increased by the addition of work in the natural sciences and in the English, French, and German languages. The tendency is to demand a broader and sounder education before entering upon the professional studies, yet the courses still contain much work which belongs to the college or to the higher preparatory school. This work is retained in the technical courses because it is considered essential to the engineer's education, but is, as yet, provided by only a few of the public high schools in which the majority of students are prepared and by the better private preparatory schools. As these latter institutions are improved, it is probable that more and more work in the pure sciences and the languages will be forced back into them and that the engineering courses will become purely technical. The time thus obtained will be used to extend the engineering courses or increase their number in accord with the growing demand.

An examination of the courses in civil engineering now offered will make it clear that the non-technical subjects now occupy between one and two years of the student's time. Rhetoric and English composition commonly require five hours per week in class for a half year or a year, but there is nothing in the work peculiar to the engineering school. There is no doubt that engineers need a thorough knowledge of English; the great majority of them are notoriously deficient in that branch; but a thorough knowledge of the technique of the language should be demanded for entrance; then the thesis, specifications, and reports, which should be greatly increased in number, should be submitted to the English department for criticism. And throughout the course a moderate amount of time, say one hour per week in the class room, should be devoted to direct instruction in the preparation of engineering documents. As the courses are now arranged, the instruction in rhetoric and elementary composition is given during the Freshman year and, if work in advanced composition is required, it is deferred till the Junior or Senior year. In the meantime, only perfunctory attention is given to the construction of the few papers required, and the facility given by the Freshman work is lost through misuse; consequently, the Senior engineering student in the advanced English classes is a pitiable object.

The studies in French and German required for entrance enable the student to parse and to read easy prose. In the course, a portion of the Freshman year is devoted to reading scientific articles in order to give the student familiarity with scientific terms. The result is a very ordinary reading knowledge of the languages, not enough to enable the student to read the German and French technical papers with facility and pleasure. Consequently, by the time he has completed his course and is ready to take up the great search for engineering information on his own responsibility, he finds so little of the languages at his command that he generally gives them up and depends entirely upon what he finds in English. Until the time arrives when a thorough reading knowledge of both languages can be required for entrance to the engineering course, better results would undoubtedly be obtained by devoting to one of them all the time now spent upon both. This would provide a satisfactory working knowledge of one language, which, in any event, is much more serviceable than a smattering of two, and practical use of one language would generally induce the young engineer to take up the study of the other as opportunity offers.

Qualitative and quantitative chemical analysis should also be required for entrance to the engineering course, though a short course illustrating their application to engineering work is desirable. The enthusiasm of the pure scientist would add greatly to the student's interest in chemical study, while the special technical course would provide the practical phase of the subject.

Mineralogy, petrology, and geology are also quite as satisfactorily taught in the college as in the technical school.

We must agree that the higher course in algebra and the courses in analytic geometry and in differential and integral calculus should be taught in the engineering school where their application to technical work may be kept constantly in view, but the lower courses in algebra and the courses in plane and solid geometry and in plane and spherical trigonometry may very satisfactorily be required for entrance.

A thorough course in elementary physics should also be required for entrance, but the advanced courses should be given in the engineering school.

When the work discussed above is done in the college (the elective system makes this easily possible) or in the preparatory school, about one and one-half year's work will be removed from the engineering course, providing time for a very substantial increase in the professional study. The additions to the requirements for matriculation and the corresponding increase in the amount of technical work in the courses which have been made in recent years clearly indicate that this procedure will continue until all cultural studies will be demanded in preparation and only technical courses will be offered in the engineering school.

What subjects should be comprised in a course in civil engineering and the amount of time and attention which should be given to each will always remain matters of discussion. The practitioner, who is nearly always a specialist, will naturally place the greatest importance upon the subjects included in his specialty or allied to it. He may possess the greatest attainable breadth of view, yet his opinions will be influenced by his work. And the instructor is a specialist in hardly less degree than the practitioner. Free and full discussion among the various members of the profession, teaching and practicing alike, will do much, and the work of the Society for the Promotion of Engineering Education promises to do more to harmonize these widely varying opinions and bring about a reasonable degree of uniformity in the courses offered by engineering schools throughout the country. Much has already been accomplished in this direction, and as the science of civil engineering grows and develops the schools must continue to adapt themselves to its needs. New branches are constantly coming into prominence, and some of the older ones are losing in importance by comparison. The production of structural steel greatly modified the designing of bridges and made possible the construction of tall office buildings. Improvements in the manufacture of Portland cement and the development of methods of reinforcing concrete have brought concrete construction into great prominence within a very few years. The discovery of large supplies of asphalt revolutionized methods of paving streets. These and similar developments demand constant growth in the courses in engineering instruction, a casting out of the old and no longer useful, and a taking on of the new and growing lines of work. Consequently, no course, ideal or practical, can be established once for all. Dr. Waddell's ideal course of eighteen years since is still far in advance of the courses offered, but it would, no doubt, be materially altered if he were to recast it to-day.

When the civil engineering course is limited to technical work, the requirements for entrance will probably consist of the following subjects:

Algebra through quadratic equations and logarithms.
Plane and solid geometry.
Plane and spherical trigonometry.
A thorough training in free-hand drawing.
Inorganic chemistry.
Qualitative analysis.
Quantitative analysis.
A thorough course in elementary physics.
Descriptive and possibly structural botany.
A sound course in economics.
General history.
A reading knowledge of Latin.
A thorough knowledge of French or German, enough to enable the student to read and write the language correctly and with facility.
A sound training in English, including grammar, etymology, rhetoric, composition, criticism, and literature, a course representing at least five one-hour periods per week in class for four scholastic years.
Courses in physical and possibly economic geology.
Elementary courses in mineralogy, petrology, and astronomy.

These requirements are greatly in excess of those which obtain at present, it is true, but they fall far short of a collegiate course, the ideal preparation. The high schools of our larger cities now afford the means of attaining nearly, if not quite all, of these qualifications, and other high schools and preparatory schools are extending their courses to meet the requirements of the colleges and professional schools. Many of the state universities which form the head of the educational system in their respective states admit students from accredited high schools without examination and include in the faculty an educator of high ability whose function is to visit the high schools of the state and see that their work fulfils the universities' requirements. Thus the entire educational system in these states is unified, and the secondary schools, which are commonly taught by university graduates, furnish whatever preparation the university demands. The majority of private schools exist to prepare students for college and will adapt themselves to the conditions placed upon them by the universities and technical schools. Thus it is apparent that the standard of the engineering schools may continue to be advanced without danger of depleting the classes.

What subjects will constitute the civil engineering course of the not very distant future may be prophesied with a reasonable degree of assurance.

though the development of new materials and methods of construction will probably modify the course as it would now be established. Absolute uniformity is, of course, impossible, but the courses in the principal institutions will follow the same general lines and would be laid out thus:

FRESHMAN YEAR.

	Unit.
Analytical Geometry	1
Differential and Integral Calculus	1
Advanced Physics	1
Surveying	1
Descriptive Geometry	1
Higher Algebra	½
Mathematical Astronomy	½
	6

	Hours Per Week.
Drawing, throughout the year	6
Shop work, throughout the year	4
Physics laboratory, one-half year	4
Surveying field work, one-half year	4
One brief thesis per week	0
Criticism of theses in class, throughout the year	1

Four weeks during summer vacation to be spent on topographical surveys.

SOPHOMORE YEAR.

	Unit.
Railway Field Engineering	1
Mechanics	1
Geodesy	½
Least Squares	½
Resistance of Materials	1
Engines and Boilers	½
Thermodynamics	½
Location of Railways	½
Roads, Streets, and Pavements	½
	6

	Hours Per Week.
Drawing, throughout the year	6
Shop work, throughout the year	4
Railway Surveying, one-half year	4
Engine and Boiler Tests, one-half year	4
One thesis every two weeks	0
Criticism of Theses in Class	1

Four weeks during summer vacation on railway and geodetic surveys.

JUNIOR YEAR.

	Unit.
Mechanics of Fluids	½
Hydraulic Machinery	½
Materials of Construction	1
Roofs and Steel Bridges	2
Sewerage	½
Treatment of Sewage and Refuse	½
Water Supply and Filtration	1
	6

	Hours Per Week Throughout the Year.
Drawing	6
Hydraulic Laboratory Work	4
Testing Materials	4
A substantial thesis, every month	0
Criticism of English Work	1
Preparation of Designs	5

Four weeks of summer vacation on hydraulic surveys and on surveys for sewerage and water supply.

SENIOR YEAR.

	Unit.
Foundations and Masonry, including Reinforced Concrete	1
Steel Skeleton Mill Buildings and Office Buildings	½
Electrical Machinery	½
Specifications and Contracts	½
Suspension Bridges, Arches, and Cantilever Bridges	1
Railway Structures	½
Tunneling	½
Wharves, Piers, and Docks	½
River and Harbor Improvement	½
The Erection of Bridges and Buildings	½
	6

The preparation of designs, estimates, specifications, and contracts, twenty hours per week throughout the year.

A unit consists of five one-hour periods in the class-room and ten hours in preparation per week for one-half the school year. Except upon mathematical subjects, only the plodding students actually require two hours to prepare the allotted text-book matter, hence the instructor should advise and encourage collateral reading and study. This can best be done by offering a list of references to matter which may be found in the books and technical papers in the library, and following this by general questions on the matter. This work should not be compulsory, for a considerable number of students are unable to do much more than the prescribed work, but many of the brighter and more energetic men will gladly make use of the advice to their material benefit.

In order that the principles taught shall be firmly established, each student should prepare at least one design, with estimate, specifications, and contract, complete, for each course relating to the construction of engineering works. These designs should not be too ambitious and elaborate, or they will crowd the theoretical work into the background and thus fail in their own purpose. They should illustrate and firmly establish the principles involved, but there should be no endeavor to make the student a finished engineer and a skilled designer. The purpose of the engineering schools is to teach principles thoroughly. To teach the practice in all branches thoroughly would be a waste of time and energy, for no engineer can pursue more than his specialty and one or two allied branches. A few students know, long before the completion of their course, just what line of engineering they are to follow, and, at first thought, it would appear best to allow these men to concentrate their efforts upon their proposed specialty to the exclusion of distantly related branches, but a man so trained will lack balance, and will have frequent cause to regret such a course. The great majority of the students, however, are children of fortune, and must follow up, as best they may, the opportunities they obtain. They are unable to foretell what branches will be most serviceable to them, and it is unusual for a student to possess a strong predilection for any one line of work. It is hardly to be questioned that, sooner or later, the knowledge of any branch more than compensates for the time and labor spent in obtaining it; in fact, it is unusual to find an engineer who does not regret that he has not an elementary knowledge, at least, of other branches than those he studied or practices. Consequently, it is almost universally conceded that the best equipment with which a young engineer can enter upon his work is a thorough knowledge of the principles of all branches of his profession. He is then prepared to pursue to the greatest advantage the line of work dictated by his tastes and opportunities.

The technical graduate should be a thoroughly trained draftsman and instrument man. Ability to do useful work in the field or in the drawing room will gain employment for him readily. He may not be very extravagantly compensated for his labor, but he will obtain his living and the opportunity to gain valuable experience. At present even the best of our institutions send out men who are utterly unprepared to do any useful work. This is so commonly true that the recent graduate is looked upon as a hindrance rather than a help, and his services are not wanted at any price in many establishments. If he were even able to make a first-class tracing with neat but plain letters and figures, his services would be of value, but generally he exhibits some laboriously prepared Whatman paper drawings with lines of irregular width and with crude lettering as evidence of his ability as a draftsman. Consequently, there is no vacancy and he continues the weary search. Order, accuracy, completeness, and a workmanlike appearance are the essentials of a good drawing, and there is no good reason why a student should not acquire them all during his course of study. Much time is wasted in the schools on old English alphabets and titles, fancy letters, shading, and similar work. Not one student in ten has the native ability to become an artistic draftsman, but every one can learn to make good, neat, practical drawings. The student is commonly required to make a complete pencil drawing; when that is completed his interest flags, and the tracing, which should be the result sought, is made in a half-hearted manner, and shows it. The subject of the drawing, be it a bridge, a dam, a pier, an engine, a boiler, or only a detail, should be worked out clearly and accurately, but by no means fully, on the paper, leaving the fine work and the finishing touches to be done on the tracing. When the student has learned to do good, clean work with facility, he may take up the more elaborate classes of work with advantage. Illuminated texts, old editions, and fine bindings are eminently worth while if one can afford them, but they are a luxury, and the taste for them should be indulged only after one has accumulated a working library.

Every civil engineering student should be thoroughly drilled in the use of field instruments and should be competent to make any kind of a survey. Comparatively few engineers will pursue field work as a specialty, but every one, especially every railway engineer, will occasionally find it necessary to use surveying instruments, and the work done in school should be so thorough that it will never be forgotten. Like drawing, field engineering will be the means of obtaining the young engineer his opportunity to gain experience, for his services in that line have pecuniary value.

The civil engineering student should do enough shop work to give him a clear understanding of the capacities and limitations of machine tools and ordinary facility in their use. There should be no attempt to make a skilled mechanic of him, but familiarity with methods of fabrication and manufacture will be very helpful to him in designing.

The English work of the course is of the utmost importance, for good or bad English will make or mar the engineer's work at every step. The successful engineer, using the term in its broad sense, must possess the forensic skill of the salesman in order to obtain engagements and develop the financial phases of his propositions, the clearness and fulness of the lawyer in the preparation of his contracts and specifications, the clearness and brevity of the business man in his business correspondence, and the skill of the writer in preparing the results of his investigations and the descriptions of his constructions for publication and record. The principles of rhetoric and composition upon which this large knowledge of the subject is based should be gained in the preparatory course of study, but their practice should be vigorously pursued throughout the entire engineering course. The brief, weekly theses of the Freshman year should develop readiness and order in expression and give further opportunity to establish the laws of composition firmly through helpful criticism. The more ample papers of the Sophomore and Junior years should be devoted to the description of engineering works, examined personally or studied in the technical press, and to such original investigations as the student may be led to make. This would afford an excellent method of compelling attention to current technical literature, a habit which the student cannot form too early. And finally, the preparation of specifications and contracts for the courses in which designs are prepared afford opportunity for the highest training in technical English. The instructors should be especially prepared for this particular work and should be engineers as well as specialists in the English language.

Especial attention should be paid to the manner in which the student does his work. If one may judge by the habits of recent graduates, it would appear that little or no attention is ordinarily given to the order in which the work should be done. The young engineer will often calculate and design the bridge trusses before he does the floor system. In the design of almost any structure there is an order in which the calculations of stresses and sections should be made, and there are fundamental conditions which govern the economical preparation of a drawing. Careful instruction in these and similar matters will save the student much time and labor and temper and will lend the zest of satisfactory progress to all he does.

Most graduates are also grossly deficient in orderly habits of recording and preserving their calculations and estimates. It is frequently impossible for another or for the engineer himself sometime after they have been made to read a set of calculations, because parts of the computations and even essential data are omitted. Portions of the work will be done on scraps of paper which are thoughtlessly destroyed, sketches will be omitted altogether or will be so crude that they are unintelligible, and the records will be rolled together without order. These habits are exceedingly vexatious both to the young engineer and to those who are responsible for his work. It should be an easy matter to drill students in orderly methods and clerkly habits, and no good excuse can be found for the general failure in this respect. It is possible to become a slave to system, but system is an indispensable aid and merits the most careful study.

The instructor often resents the practitioner's criticisms of the course of study and the methods of instruction. Teaching is his branch of the profession and he considers himself in the better position to judge of methods and subjects. He is constantly engaged in the work for three-fourths of the year, whereas the practitioner rarely visits the institution. But he must not lose sight of the fact that he is being judged by the results of his work, the knowledge and skill possessed by his students, just as the practitioner is judged by his finished structures and their operation. The engineer in practice employs young men recently from college, and in doing so he is purchasing the results of the professor's work, the training, the knowledge, and the technical skill, as well as their energy and intelligence, and he is certainly in the best position to know whether he obtains what he desires. It is hardly essential to point out that what he demands and is most willing to pay for is also what is best for the employee and, consequently, what the instructor should furnish the student.

The four years' technical course in civil engineering and the preparation for it outlined above are, in the editor's opinion, essential to the satisfactory education of a civil engineer; anything less leaves fundamental deficiencies, and more preparation would be an advantage. The crying need of the hour in the profession of civil engineering is for better trained men. Men of indifferent training are abundant and their services may be obtained for a small price; but men of exceptional training and ability are eagerly sought. It is a common occurrence to find graduates of our better engineering schools who are grossly ignorant of fundamentals, clearly showing that their training had not been so thorough as it should be, even in the courses pursued. For instance, one exceptionally bright man, in making the calculations for a mine hoist, insisted that the percentage of grade and the angle of slope are identical; another spent several hours calculating the ordinates between the center line of a plate girder bridge and the center line of the track, the point of curve being on the bridge, and then his work was erroneous. These men both graduated from one of our best engineering schools. And numerous similar failures have been observed in the engineers who have come under the editor's direction. Lack of thoroughness, both in knowledge and in method, is so much the rule that until the character of a man's work is known from experience, it must be looked upon with suspicion. No more work should be required in an engineering course than the student can perform well, if he be reasonably diligent, and thoroughness should be the instructor's watchword. It is infinitely better to omit some courses and teach the others thoroughly, than to cover the larger number more superficially, for the energetic man will struggle to make good his lack of breadth, but the ill-grounded man generally remains ill-informed.

The courses in mathematics, physics, and mechanics should be given from text-books and supplemented by lectures. The writer will always recall with much pleasure an informal lecture on analytical geometry which made the value of the course and the possibilities of the subject exceedingly clear and attractive and which greatly increased the general interest in the subject. The value of such lectures cannot well be estimated. They should be given as often as the subject furnishes matter and are all the more satisfactory if informal, for in lectures of that character the student feels the instructor's personality much more than in formal lectures. If the student be not thoroughly drilled in these fundamental subjects, his whole course is weakened, for he will come to his professional studies ill-prepared and will grope his way through them.

In the purely professional studies, instruction in theory and practice go hand-in-hand. The theory is undoubtedly the more important, for it is possible to attain the knowledge of the practice later, but instruction in the practice of a subject serves to arouse interest in the theory and fix it in the student's mind, to make it a matter of understanding rather than memory. And, if the instructor keep in close touch with the latest designs and construction in his lines, the student will enter upon his professional work with a knowledge of current practice rather than that of the text-books which must of necessity be at least two or three years old. Practice develops so rapidly nowadays that very material changes are often effected within two or three years.

A brief, fundamental course in graphics should accompany the courses in mechanics, and graphical as well as analytical methods should be taught thoroughly in all the professional courses. The graduates of European technical schools are much better grounded in graphics than Americans. The analytical methods should, however, be so thoroughly taught that they may be used entirely if desired. The best trained engineers will use both methods.

Short cuts, methods of approximation, the degree of accuracy which is desirable, and methods of checking should be well taught. Not long since a prominent bridge company published and distributed widely a set of specifications containing several tables of bending moments, shears, and equivalent uniform live loads for railway bridges. Before using them the editor checked them and found almost every figure in error. When the matter was brought to the attention of the bridge company's chief engineer, he admitted the error and stated that the calculations had been twice independently checked, but investigation showed that the work had been done graphically and both checks had been made by scaling the original diagrams, which were in error. Graphical work should invariably be checked analytically. One or two analytical checks will determine the correctness of the graphical calculations of the stresses in a truss.

Instruction in the methods of arriving at costs is of the highest importance. The current cost of materials and labor is a less important matter. But it should be made very clear that interest, depreciation, superintendence, contractor's profit, risk when plans are not clear, conditions governing erection, strikes, fire risks, obscurities in specifications, fluctuations in prices, and other contingencies are quite as important factors in preparing a true estimate as are the essential materials and labor. Engineers without business training are almost invariably deficient in ability to prepare an estimate quickly and closely in accord with the actual cost of construction. Little credence is generally placed in the young engineer's estimates, for he is seldom well prepared to make them, and he learns correct methods only through grievous blunders which are expensive to his employer and damaging to his reputation.

Methods of filing and indexing, though a clerical matter, merit close attention, for the recent graduate usually knows nothing about them and, consequently, does much work a second time, because what he has done is not available for use.

Trade catalogues and hand books are exceedingly beneficial in the actual information they contain, in arousing interest in construction, and in pointing to the application of the theoretical instruction. Sets of catalogues, properly indexed for ready reference, should be available for illustration in the class rooms, not in the general library. Manufacturers are, as a rule, glad to furnish a liberal supply of printed matter, and will often donate photographs of plants and of individual machines.

Increasing attention is being given to æsthetics in design, but instruction in that line is still in a primitive state. The elementary principles of architecture should be taught, and much attention should be given to appearances in the preparation of designs in the professional courses.

Instruction in methods of original research is best given by requiring the student to make some original investigation as the basis of a graduating thesis. There is not time for more than one such investigation, and too often this is a farce.

Good text-books are much more abundant than they were when Dr. Waddell's paper on Civil Engineering Education was written; in fact, in most subjects there are several good ones and some that are obsolete. It is one of the instructor's first duties to be thoroughly familiar with all the available text-books in his lines of work. He should review the new books as soon as they are issued and satisfy himself that the one he is using is the best obtainable. It is not rare for a professor to become satisfied with the book he is using and continue to use it long after something superior is published. Sometimes, too, friendship for its author unduly influences the choice of a text-book.

Frequent references by the professor to current technical literature will arouse the students' interest in the courses and in the technical periodicals.

Attention should also be called to historic structures, the greatest bridges and their chief peculiarities, the greatest canals; notable river, harbor, and channel improvements; prominent examples of the various methods of filtering and softening water; and notable feats in railway construction. The failures as well as the successes merit attention, for both contain their lessons. The student should be advised where he may find descriptions of such works and thus induced to make full use of the library. A card catalogue and a well-filled book stack rather appeal with their mass. The student knows that he can read but little of what is available and hesitates to select at random, but he can be easily interested and led to read much and advantageously. Much of his time may be saved and error be avoided if the instructor will point out those portions of old books which are obsolete and those portions which merit attention. A list of books or portions of books which bear on it and a statement of their relative importance should be posted at the beginning of each course.

The formation of technical societies within the institution is also very beneficial, for it affords opportunity for the student who has visited engineering works or spent a portion of his vacation in some engineering office or works to describe them and thus gain facility in expressing his ideas and give the others a glimpse of what comes after graduation. These societies may be instrumental in obtaining very valuable lectures from practicing engineers. They also tend to unify the student body and intensify interest in the subjects under discussion, and they afford opportunity for healthy rivalry in a strife for prominence.

In practice the engineer studies his subordinates in order to keep them fully occupied and to obtain the best results. They must be kept employed as far as possible on work which interests them, and a word of encouragement is well worth while. In fact, a personal interest is exceedingly profitable, both to the engineer and to his assistants. The instructor has even greater reason to study the character and mental processes of his students and to take a personal interest in them, for the results of his life work are the knowledge he imparts and the influence he attains and exercises, and there is little influence unless there be a strong personal interest. The personal relations between the student and the professor are chiefly dependent upon the latter, for he is older, has the stronger personality, and may readily read the younger man's character and learn how to influence him. The student is in a large measure as clay in the professor's hands. However, he stands somewhat in awe of his superior's years, learning, and authority, and must feel the instructor's interest and encouragement if they are to meet on common ground.

The well-prepared student should know how to study, but a watchful instructor can frequently help him to better methods. For instance, a diagram of the contents of a book, showing the principal subjects with their sub-headings and their relations to each other will assist the understanding and aid the memory. The student should prepare such diagrams of the books he reads and of his text-books when he has finished a course. After hearing a lecture, notes upon it should be prepared for reference. A meagre skeleton can be made during the course of the lecture, if the student be well trained in English composition, for, in that event, he will readily determine the salient points as the lecture proceeds. Any attempt to make full notes during a lecture will result in a deficient comprehension of the subject matter, for the mind cannot simultaneously follow the lecturer's thought and formulate notes. There are a great many other helps which are matters of routine to an instructor, but which the student will acquire only after much waste of labor if they are not brought to his attention.

The work of the instructor is higher in character than that of the engineer in practice, for he builds men, not structures. He exercises, if he will, a strong moral influence upon young men who are in the formation period of life, hence most susceptible of control. He teaches them facts and how to use them, how to study, how to think, how to carry themselves toward their fellows. His responsibility is great, but his reward is greater. Year after year men go out from his guidance and take their places in the world, extending his influence and bearing a kindly regard for him through life. In public esteem no other calling occupies so high a place, unless it be that of the clergyman. These considerations, the pleasant character of his work, and the imperturbed life, form no small portion of the professor's compensation, and make his position desirable, even though his salary is rarely more than enough to enable him to live as befits his station in life. Consequently, competent, even eminent instructors, may readily be obtained for a much smaller salary than they could command in active practice. It is too frequently the case, however, that the salary allotted for a position is insufficient; then cheap or inefficient men, men who follow teaching because they have not the energy to practice, are obtained and the students and the institution suffer. The practice of employing men just graduated to fill lower positions in the faculty deserves severe condemnation. Such men, however well educated and capable they may be, lack the breadth and the knowledge of the professor's requirements, which an instructor in any grade should possess. Even one or two years of practice, though the work obtained be of a low grade, will add greatly to the instructor's breadth and to his knowledge of the practice of the profession.

Instructors who have not the opportunity to do practical work during the school year might spend a considerable portion of the summer vacation in the shops or on construction. Temporary positions are often difficult to obtain, it is true, but they are not impossible. It may be objected that the vacation is for rest, but the engineer in active practice works quite as hard as the instructor, yet gets a vacation of not more than two weeks or a month, often none at all, during the year. And the change from teaching to construction should in itself afford much of the required rest.

In teaching, as in practice, it is the active, energetic man who succeeds. The instructor is considered inferior to the practitioner only by second-rate men who are themselves weak in theoretical work and who seek to minimize their deficiencies by insisting that practice is all. Lazy, ill-prepared, and impractical men are held in low esteem in any branch of the profession, but it is a deplorable custom for institutions to retain such men through a mistaken consideration for them, instead of setting them adrift, as would be done in the business world. The lazy instructor does not keep up with the growth of the science and is content with work which is below standard. Consequently, his students are ill prepared and have lazy habits, too. The mere teaching machine, who is conscientious but has not ability, is quite as bad as the lazy man.

The professor should have time for reading, study, original research, and visits to plants, works under construction, and other institutions; but too much spare time is almost as bad as not enough, for no man with too much leisure will remain energetic. Too much work does not leave time for breadth and judgment.

The editor is without experience as an instructor; consequently, his ideas of methods of instruction are of doubtful value. Yet it may be worth while to state a few of them. He has painful recollections of an instructor who could not or would not touch upon any phase of the subject under consideration that was not to be found in the text-book. Nothing could be more dreary than to work over again in class just what is already clearly understood from the text-book, without amplification, illustration, or application. The discussion should not hinder a full examination of the text-book matter, but the value of the instructor's work depends chiefly upon his ability to make the subject real and interesting. Free references to other books on the same subject, illustrations of the application of principles, digressions, and amplifications which tend to make the subject clearer are all valuable, and, if employed judiciously, do not mitigate against thorough drill on the text-book.

The lecture system lacks the advantage of reiteration, which is responsible for thoroughness. The consultation method described by Dr. Waddell is admirable for the professional courses when students are thoroughly in earnest. Every able instructor uses it more or less. But it affords an excellent opportunity for the glib, quick-witted, and lazy student to make a better showing than his knowledge warrants, while the diffident or slow student will rarely do himself justice. If the professor be keen enough to detect the lazy, superficial man's unsoundness and prevent him from monopolizing the discussion for the sake of appearances, to search out the reticent student's hidden knowledge, and to withstand that subtly applied flattery which is designed to keep the instructor talking while the student remains idle, the largest possible amount of work may be done under this system, for a great amount of repetition which is uninteresting and often unnecessary will be avoided. In the hands of the plodding, the easy-going, or the susceptible instructor, however, the results would be doubtful, to say the least.

The best method of instruction must, however, be largely a matter of the instructor's ability. Some men are able to obtain thoroughly satisfactory results, even in theoretical subjects, by using the lecture system; others adopting the same method would fail lamentably. For the able lecturer the recitation system is distastefully slow and plodding, while others to whom lecturing is impossible obtain excellent results by means of text-books and recitations alone. The good lecturer, however, will generally be the more successful in arousing interest and enthusiasm.

What constitutes a reasonable or passing knowledge of a subject is not easy to determine. In the daily recitation the quick-witted student will appear to much better advantage than his slower and often sounder fellow; a nervous man of the highest intelligence may fail utterly; and the fluent talker will often be able to cover his weaknesses well. Most students approach a final examination with fear and trembling; the nervous man will lose his wit completely, and the slow man will not have time to complete the work. The best plan seems to be to base the judgment of a student's fitness upon the daily recitation, the final examination, and the short, unexpected examination commonly known as the "quiz," which is given at intervals during the term. The last is a particularly good test. It is suitable for the nervous student, for it is commonly the anticipation of the examination that unsettles him, and it is exceedingly effective in keeping the daily work up to the standard. When it will be required is unknown, hence the student must always be prepared for it. This is of very great advantage in the work, for the student who gets behind in one subject generally makes his deficiency good at the expense of another.

In a large measure the class should be allowed to conduct the review, each student bringing up for discussion and elucidation the points which trouble him. By dividing the subject into portions corresponding to the time allotted for review and confining the questions of a period to the portion designated for that day, the whole will be made clear and the student will be fully prepared for the final examination.

Examinations should, if possible, correspond to the test of knowledge which will occur in practice. In the professional courses the student should be allowed to make use of the tables and hand-books, which will save numerical work and furnish ordinary data, such as weights and properties of sections, weights of materials, logarithms, and natural trigonometric functions. The examinations conducted by the United States Navy for the selection of civil engineers are excellent examples of a test of knowledge. The object of the test should be to determine the extent to which a course has been assimilated and made ready for use, rather than how much is remembered.

The degrees which should be conferred upon the completion of technical courses are still the source of much discussion, though a great number of the better schools now confer the degree of Bachelor of Science upon completion of the undergraduate course in civil engineering, followed by the degree of Civil Engineer upon presentation of a thesis and after two or three years' practice; some equally prominent institutions offer the degree of Civil Engineer upon graduation and Master of Civil Engineering for a year's resident or two years' non-resident work. The graduate is probably as much of an engineer as a graduate of a medical school is a doctor, and he is quite as much entitled to a professional degree. Yet he is by no means an engineer. Neither is it at all apparent that two or three years' practice and a thesis make him one. The practice may be of such character that he will forget what he knew at its beginning. In more than one case which has come under the editor's observation, graduates of the best schools have, after two or three years in the drafting rooms of a bridge company, forgotten how to calculate the stresses in a simple truss. It is needless to say such men are not civil engineers in any true sense, yet, under the arrangements mentioned above, they would be entitled to a professional degree upon presentation of a thesis.

In the writer's opinion, the graduate of a course such as Dr. Waddell describes in his paper on Civil Engineering Education, or as outlined above. has earned a professional degree. He is well grounded in the theory of all important branches of his profession and is by no means without knowledge of the practice. In all probability he will never be much better informed in many lines of work, and it seems unjust to withhold the degree of Civil Engineer and confer upon him that of Bachelor of Science instead, a degree conferred by all grades of institutions upon completion of courses, good, bad, and indifferent, in the pure sciences. The fact that the courses now offered are generally far below the standard Dr. Waddell has suggested does not materially alter the situation, for the difference is one of degree only, and that difference is being steadily diminished.

The engineering sciences have advanced with marvelous rapidity during the last half century, but especially during the last twenty or twenty-five years. Discoveries in pure science have followed each other in rapid succession and new branches of engineering are founded upon them. Not only each decade but each year sees distinct advances in engineering practice. Engineering schools have increased in number and size to meet or even in anticipation of the demand for engineers, but the courses have not been improved proportionately. Material advances have been made in the equipment of the schools, in the requirements for admission, and in the requirements for graduation, but the demands of the profession have advanced still more rapidly. The greatest present need is for more thoroughly trained men, and the technical schools must supply them or fail in their full purpose. More work must be required of the graduate and the work done must be more thorough. How this is to be accomplished is the great problem now confronting the governing boards and faculties of the engineering schools.

THE ADVISABILITY OF INSTRUCTING ENGINEERING STUDENTS IN THE HISTORY OF THE ENGINEERING PROFESSION.

INTRODUCTORY NOTES.

The paper entitled The Advisability of Instructing Engineering Students in the History of the Engineering Profession was prepared for the annual meeting of 1903 of the Society for the Promotion of Engineering Education. It is very evident from the amount and quality of discussion it provoked that the subject is of general interest to engineers. The comment is, almost without exception, favorable to the preparation of a comprehensive history of civil engineering, using that term in the broad, inclusive sense. The very great need of instruction in the history of the profession is almost universally admitted, but there is, of course, diversity of opinion regarding the amount of time which should be devoted to the subject. In the present crowded condition of the technical courses, it would be difficult to do more than devote to it a few periods at the beginning of each course, but that time would be exceedingly well spent, for it would convey some general ideas and so interest the student that he would undoubtedly employ a portion of his spare time in reading the available literature on the subject. The editor knows from personal experience that earnest students will read eagerly any matter that will throw light upon the work of their chosen profession.

Whether the Society for the Promotion of Engineering Education should assume the task of preparing a History of Engineering is purely a matter for that Society's consideration, and the discussion of the advisability of its doing so would be out of place here. There can be no question, however, about the propriety of such an organization doing the work, for its members are chiefly professors and probably have more time for such work than practitioners do. They also have the use of the libraries of the institutions in which they are employed, and are directly interested in presenting the subject to their students.

The form in which the book is published is of small consequence; that the work be prepared and made available for use as early as possible and that it be thoroughly done are the main objects. To prepare a monograph relating to each branch and publish it as soon as possible would undoubtedly get the work started more quickly than to make a single task of the whole, for there are certainly professors so well versed in the history of their specialties that they could prepare the matter for the press at once, and the publication of one or two monographs at a time involves less immediate expenditure of money. The final cost of a number of volumes would, however, be greater than that of a single comprehensive work.

It is generally true that a number of small volumes dealing with separate portions of a large subject will be bought and read much more widely than a ponderous work covering the whole subject. The very size of the latter deters one from undertaking its perusal until more time is available, a condition which rarely occurs.

Dr. Waddell's habitual persistence in the pursuit of a good cause makes it certain that something more than discussion will result from his idea, and once the History of Engineering is available, there is no doubt that it will be widely read and very generally given a place in the curriculum of the technical school.

THE ADVISABILITY OF INSTRUCTING ENGINEERING STUDENTS IN THE HISTORY OF THE ENGINEERING PROFESSION.

The absolute ignorance of students at engineering schools, of young engineers, and, it must be confessed, also of many old members of the engineering profession, concerning the history of civil engineering and the names of the prominent engineers of past and present times, is simply astounding!

Why should such a deplorable state of affairs exist?

Some may say: " Because ours is such a recent profession, it being, in fact, the youngest of all the learned professions." Although in one sense this statement may be correct, still the excuse will not suffice; for civil engineering is, in fact, one of the oldest, if not actually the very oldest, of all the professions. In prehistoric times the men who dammed water to irrigate their fields, or who crossed streams by felling trees or by piling rocks in their beds for stepping stones were certainly the engineers of those days—and it is more than likely that there were then no lawyers, doctors, or clergymen, because law, medicine, and religion were probably unknown.

Others may reply: "Ours is such a busy profession that its members are ever occupied with the present and looking to the future, so have no time to spare for considering the past." This is a good reason but a poor excuse. Moreover, now that the general public recognizes engineering as one of the learned professions, it behooves its members to become conversant with its history and development and familiar with the names and careers of its most prominent men.

Others may say: "The blame lies with the professors of engineering in the technical schools, who pay no attention to such matters as engineering history." This is true in a way; but the professors might reply: "There is no time in the curriculum to devote to such matters, for there is already more in our courses than can be crowded into the allotted time" —a lame excuse, indeed, because either the time should be increased or something of less importance should be left out—preferably the former. Or the professors might answer: "How can we teach the history of engineering when there is not a single book of any value upon the subject, and when we ourselves are nearly as ignorant thereon as our own students?"

Now we are arriving at the gist of the matter; for if there were in existence a thorough, reliable, and exhaustive history of civil engineering, it is probable that every professor in every technical school would use it to a greater or less extent, and most of them would adopt it as a text-book.

But who is to undertake the stupendous task of writing such a treatise? No one man could do it in any reasonable time; and, moreover, no one man is capable of doing it properly; consequently, if the book be written at all, it must be prepared by a combination of writers.

Now what combination of engineers and technical writers is as well fitted for such work as the members of the Society for the Promotion of Engineering Education?

And what a grand enterprise it would be for this Society, one that would make it famous for several generations throughout the entire English-speaking world! Aye—more than that—throughout the whole civilized world, because such a valuable book would certainly be translated sooner or later into the principal foreign languages.

Such being the case, let this Society appoint a committee to first consider the advisability of the Society as a body undertaking the writing and publication of "The History of Civil Engineering," using the latter term in its broad sense so as to cover all branches of engineering except the military; and, if the decision of the committee be favorable to the suggested publication, let it outline in its report a policy and *modus operandi* for the Society to follow in order to produce the best possible history in the reasonably shortest time.

The following are some suggestions that the writer would offer concerning the proposed work:

1. That the subject of civil engineering be divided into a number of heads or topics representing the different kinds of engineering work, and that these be apportioned among the members of the Society, one topic being given to one member, or perhaps in certain cases to two or more.

The following is offered as a preliminary list of topics, to be amended or increased as may seem good to the committee:

Bridges.
Concrete and cement.
Dams.
Electrical engineering.
Engineering education.
Foundations.
Gas motors.
Harbors.
Hydraulic motors.
Landscape engineering.
Manufacture of iron and steel.
Masonry.
Mechanical engineering.
Mining engineering.
Power transmission.
Railroading.
Rivers and canals.
Roads, streets and pavements.
Roofs.
Sewerage and sanitary engineering.
Shipbuilding.
Steam engines.
Steel buildings.
Surveying and geodesy.
Tunnels.
Water supply.
Wind motors.

It is to be noticed that this list is made alphabetically, which is the arrangement that the writer would suggest for the book.

2. That an editing committee of three be appointed to choose the various writers, apportion their subjects, limit the number of words and illustrations for each subject, check, correct, and finally approve each finished paper, and attend to the publishing of the entire book, the proof-reading of each article, however, being left to the writer thereof.

3. That the committee collect to as great an extent as possible the portraits of the leading engineers of the past, and reproduce them throughout the book in the papers devoted to their principal specialties or finished constructions.

4. That the committee collect also photographs of a number of the principal constructions pertaining to each division of the book, and use them for illustration.

5. That the various writers be advised to call for suggestions or aid on their work from other engineers, whether the latter be members of the Society for the Promotion of Engineering Education or not, and from the various engineering societies both at home and abroad.

6. All papers should be written with the understanding that the main usefulness of the book will be through its perusal by students in technical schools.

7. It will be necessary for all writers to treat as fully as practicable the work of foreign engineers as well as that of their American brethren.

8. Only reasonably authentic history should be given; and wherever there is any doubt whatsoever concerning the correctness of any statement, the said doubt should be clearly indicated, and the sources of information stated.

9. The book throughout should be written in a most readable style. It should be thorough, concise, accurate, and complete without being too lengthy.

10. The various writers should keep in close touch with the editing committee as their work progresses, so as to avoid to as great an extent as possible the necessity for changes.

11. No expense should be spared to make the book complete and to publish it in first-class style.

12. The selling price should be a minimum; and if eventually there be any profit, it should be divided into two equal parts, one part going to the general fund of the Society, and the other being divided equally among the writers of the various papers, including, of course, the editing committee.

13. All actual cash expenditures by the writers in preparing their papers should be repaid immediately by the Society from a preliminary fund established for the purpose. This fund should be used also in securing portraits of the old engineers and photographs of important engineering constructions.

14. It would not take a large sum of money to publish the work, because the typesetting, paper, printing and binding need not be paid for till after the book is issued; and the initial sales would certainly cover all such expenses.

15. The sale of the book, even at the outset, would be immense; and afterwards the demand would be both large and constant, rendering the venture a financial success and the work the most popular and widely used of all engineering treatises.

DISCUSSION.

[The Secretary received a large number of written discussions of Mr. Waddell's paper. It has not seemed necessary to print all of these discussions in full, but such extracts as will put the reader in possession of the numerous opinions and arguments that were elicited bearing upon the important proposition submitted by the essayist.—Editors.]

W. H. Bixby.—"I feel that such a compilation and publication is exceedingly desirable by some responsible party or parties, and I would gladly see it done if possible by the Society for the Promotion of Engineering Education."

Charles Puryear.—"The chief benefit of such a course of instruction would, in my opinion, be derived from the fact that it would enable the engineering student to view his intended profession in true perspective and give him a definite idea of the relation of the engineer to society.

"I believe the plan proposed for bringing out the history is, on the whole, a good one; but I think there would be lacking the unity which should characterize a book; and that the result would be not a 'book' in the best sense, but a cyclopedia of engineering history.

"It would, in all probability, be too bulky to admit of its being given a place in the already crowded curricula of engineering schools. But the material once gathered and published in a form acceptable to practicing engineers, it would be an easy matter to prepare a text giving the essentials of the subject in condensed form; this might well be given a place in the schools.

"I think it would detract from the book to insert photographs of engineers; and I disagree with the suggestion that 'the sale of the book from the outset would be immense.' "

S. N. Williams.—"I wish to express my hearty approval of the new and admirable thought of Professor Waddell. The wonderful achievements of engineering skill have not been properly appreciated by humanity as compared with like productions in other professional lines, while the known modesty of engineers has caused an unwillingness to press their claims for recognition on the public which has been surfeited with histories of all kinds and persons excepting those who have in an engineering way contributed so materially and quietly to human welfare.

"The time has fully come for this neglect to be remedied, and as the justice of Professor Waddell's statements will immediately commend itself to the members of our Society, I trust steps will at once be taken to prepare such a history along the lines he recommends.

"This movement harmonizes admirably with the grand offer of Andrew Carnegie to build and maintain a home for the various engineering professions, thus doing a noble work in educating the people of America to a proper recognition of the great service engineering has done for the world which has never been more conspicuous than at the present time.

"I favor also the detailed suggestions made for the preparation of this history."

L. S. Randolph.—"The writer is heartily in accord with Mr. Waddell on his ideas, and believes that such a history as he advocates will be extremely valuable. One of the great values of history and the study thereof is that it gives a man more definite conception than he will otherwise get, and there is no doubt in the writer's mind that definite conception in regard to what constitutes an engineer and what an engineer should be are not only badly needed among the people generally but also among those whose duty it is to train and teach engineers.

"The multiplicity of scholastic degrees with the word 'engineer' attached, and the planning of many of the courses of instruction in engineering, are proof positive of the absolute necessity for some more thorough knowledge of the work of an engineer. The civil engineer retains more than any other class his high position. By civil engineer is meant all of those included in the broad term of civil engineers, with the exception of what are sometimes called dynamic engineers. In one or two of the old schools of engineering, which for thirty or forty years have been turning out civil engineers and which therefore are thoroughly acquainted with the history of the same, the course of instruction is well fitted to the work to be accomplished and the professional standing of those practising the profession is more thoroughly recognized.

"The danger comes from those who, having nothing of the training and preparation for their work which is given to the civil engineer, seizing upon the title of such high renown and boldly appropriating to themselves the accompanying unearned honors and emoluments. We have the man who fires the boiler and pulls the throttle dubbed a locomotive or stationary engineer; we have the woman who fires the stove and cooks the dinner dubbed the domestic engineer, and it will not be long before the barefooted African, who pounds the mud into the brick molds, will be calling himself a ceramic engineer. Those of the teaching profession have seen how this thing goes and are familiar with the tonsorial artists who are called professors, and the dancing masters who have the same high sounding title.

"In order to place the matter briefly it can be said that the profession of engineering is to-day at the parting of the ways. If the engineer is to fulfill the definition which is so generally accepted, 'as one who applies the discoveries of the scientists to the structural needs of mankind,' something must be done at once, and there are but two ways of handling the question. One is boldly to adopt a new title and leave the title of engineer, which is rapidly falling into disrepute, to locomotive engineers, the domestic engineers, the sugar engineers, etc., who have caused its fall. Or to begin a campaign of education which shall bring clearly before the public, before our college presidents and boards of control, what the engineer is, or rather what he should be, and I know of no better place for this to be done than in this Society, and of no better method than the preparation of a history of engineering as outlined by the author of the paper."

H. W. Tyler.—"Your circular note of May 21 in regard to the advisability of instructing engineering students in the history of the engineering profession is duly received. The idea impresses me very favorably, as tending to give engineering students the breadth of view they need but do not always gain. I should, however, doubt the wisdom of an attempt on the part of the Society to compile and publish a treatise."

F. H. Robinson.—"I am sure there can be no question regarding the desirability of a work on the history of the profession. It would be valuable not alone to the students in technical schools, but to the entire profession. As it does not seem at all likely that an individual will take the matter up, I hope our Society will promptly do so."

A. F. Nesbit.—"I have no doubt as to the advisability of thoroughly acquainting our students with the history of the engineering profession, either by actual class-room instruction, or by requiring them to purchase recognized literature concerning the same. To illustrate this latter method, I try to put into the hands of my electrical students the best information regarding subjects, terms, phrases, history, etc., by requiring each one of them, at the outset of their courses, to purchase the enlarged edition of Houston's 'Electrical Dictionary.' Whether the result can be best attained by attempting, as Mr. Waddell suggests, to include under one head, such topics as electrical engineering, mechanical engineering, mining engineering, etc., so broad in themselves, or whether it would be better to differentiate and publish separately, I am not prepared to say. I believe, however, that some action toward the end Mr. Waddell has in mind would prove of value not only to myself and students, but to a large body of readers."

E. L. Corthell.—"If the profession could have a history of itself such as Mr. Samuel Smiles wrote years ago in his 'Lives of the Engineers' it would be of great value to the young men who are coming forward in our profession, but it should be written in an attractive style such as Mr. Smiles' was, and by someone, or by those who are capable of writing in a popular manner. I am in hearty accord with the project."

Stanley H. Moore.—"I heartily endorse the idea; one question, however, arises in my mind. If the Society undertakes the publication of such a volume, why limit it to civil engineering and give but one chapter to mechanical engineering? Why not publish a work, on the excellent plan outlined, and call it a History of Engineering?"

Walter G. Berg, Chief Engineer, Lehigh Valley R. R.—"I consider Mr. J. A. L. Waddell's suggestion for the compilation and publication of a 'History of Civil Engineering' as a very valuable one. The advance in civil engineering, like in most professions, has been by a process of evolution and experience gained not only in experimental work but in actual new construction works, built on new ideas and conceptions. Hence the history of the profession, if written not just as a record of names and facts, but as an analytical treatise of the principles and important steps in the evolution of the art, will be of great value. In addition, it might be truly said that we to-day owe it to the pioneers in our profession to record their work and to give due credit for their achievements accomplished at a time when the auxiliaries of the profession, such as technical literature, accurate instruments, records of results of others in similar fields, were practically nil."

A. H. Fuller.—"The writer feels greatly interested in Mr. Waddell's suggestions concerning the publication of a history of civil engineering and hopes to see the Society push the matter at the annual meeting.

"The writer would suggest that irrigation engineering be added to the topics already offered, and also that the topics be grouped by subjects instead of alphabetically. Under the arrangement offered by the author the matter appearing under hydraulic motors (to take a specific example) might well be expected under water power development and closely associated with rivers and canals, and water supply. With a suitable index, would it not be unwise to separate kindred subjects into an alphabetical scheme simply to make a doubtful improvement in the general arrangement?"

W. L. Miggett.—"I of course think that a history of engineering would be of great value to the profession in general, but whether it could be used as a text-book in schools is more or less doubtful because of the already numerous subjects that seem to be essential in an engineering training. His plan for compiling such a history seems feasible and I would be glad to see the Society take the proper steps to have the matter given thorough consideration."

Ellory W. Davis.—"I believe the Society would give valuable aid to both teachers and students by the preparation of some such work as Mr. Waddell suggests. We better understand present practice by seeing how it came about. We better understand how to improve that practice, i. e., actually get improvement adopted, if we see how this has been done in the past, and, moreover, not infrequently we shall avoid serious errors by seeing what similar errors have led to in the past. These are direct practical results. Hardly less important is, however, the enthusiasm created by the study of the struggles of the great ones who have preceded us."

Palmer C. Ricketts.—"I have read with interest the abstract of the paper of Mr. Waddell on 'The Advisability of Instructing Engineering Students in the History of the Engineering Profession.' His criticism of engineering schools is to some extent just. The shortcoming of the schools in this respect is, however, due partly to the same cause which compels the omission of other valuable materials—to want of time. And I do not regard this as wholly a 'lame excuse.' Everything must give way to important fundamental principles and the field is so wide, in a general engineering course, that much interesting and valuable matter must be omitted because it is not of fundamental importance.

"I agree with Mr. Waddell that the Society would be well employed in the production of a history of the engineering profession. It would in this way, I think, do more work of value to the schools and to the profession than it has heretofore been able to accomplish."

B. F. Groat.—"I favor a brief course in the history of the subject, and the Publishing of a text-book by the Society, if it proves, upon careful investigation, to be a feasible thing for the Society to do."

Mansfield Merriman.—"I am not prepared to agree with the author that teachers and students in our engineering colleges are 'absolutely ignorant' concerning the history of engineering. On the contrary, I am of the opinion that the teachers know many things about the great engineers of the past and present and that they impart some of this knowledge to their students.

I cannot admit that 'there is not a single book of any value on the subject,' although I am quite willing to agree with the author that a comprehensive history such as proposed would be of much value. The publication and sale of a historical volume of this kind is, however, a financial problem of some difficulty. It is not at all probable that 'most professors of engineering would adopt it as a text-book,' nor that 'its sale would be immense,' nor that the initial sale would be sufficient to cover the expenses of type-setting, paper, printing, and binding, and least of all that it would certainly be translated into the principal foreign languages. The enthusiasm of the author appears to have led him to make statements which calm reflection cannot warrant.

"The main thought of the author is an excellent one, but I doubt if it is expedient for this Society to take any formal action upon it. There is ample room in our Proceedings for the publication of historical papers, and I trust that some may appear in future volumes. A subject cannot be thoroughly understood until its historical development has been understood, and, acting upon this idea, it has long been my custom to give historical information in lectures to my classes. Formal presentations of the history of the different branches of engineering are, however, not as numerous in print as might be desired, and it seems to me, if one or two of these were read at each of our annual meetings and published in our Proceedings, that the cause of sound engineering education would be promoted."

Daniel Carhart.—"It is time that the writing of such a history be undertaken. We could use advantageously such a work here, and I have no doubt every technical school and scores of engineering offices would want the book. Besides, it is due the great profession which we represent that a detailed account of its beginning, its growth, its present proportions, and the men who have contributed to make it what it is should be presented in an attractive manner as to matter, page, and cover."

F. P. Spalding.—"Mr. Waddell's paper introduces a very important subject. There can be no question as to the desirability of instructing our students in the history of the profession. Probably, nearly every teacher of engineering does a little in this direction, by teaching certain subjects through tracing the gradual development of present practices and theories from their beginnings. Some subjects are most effectively handled in this manner, and little digressions into biographical sketches, or notes of related events, may often add interest and charm to the subject. Probably the detailed history of the development of a particular field of work would be best given in connection with the treatment of the subject of which it is the history, but a connected discussion of the history of engineering as a whole, with some account of the lives of the men who stand out most prominently, would be of immense value, through the aid it would give in eliminating the mere business idea and inspiring the young men with the love and reverence they should feel for the dignity and traditions of their profession.

"Mr. Waddell suggests that in writing the proposed history, the field of engineering be divided into certain specialties, each of which should be separately written by a man qualified for treating it. This would undoubtedly be the method best calculated to get a connected account of the development of engineering science and practice, and would place at our disposal the information necessary to produce the wider history of engineering as a whole, and of the men who developed it.

"The publication of these special histories as separate small volumes in a series under a single editor would seem preferable to a single large volume. And a second series of engineering biographies would be of equal value.

"For a text-book upon which a systematic study of history of engineering, in the schools, may be based neither of these could be suitable, but some one must take the materials thus brought together, and carefully arrange it into a connected discussion, showing the all-round development of engineering science and practice and the relations between its various parts.

"The writer does not now feel able to express an opinion concerning the desirability of the Society taking the matter in hand. It should first be thoroughly discussed and understood. The publication of such a work should not be difficult to arrange as a private enterprise; it only needs to be started.

"The proposition is worthy of serious consideration by the Society and it is suggested that a committee should investigate the matter, more in detail, as to its feasibility and business arrangements, before any final decision is reached."

J. L. Harrington.—"The paper entitled 'The Advisability of Instructing Engineering Students in the History of the Engineering Profession,' introduces a subject which is now almost universally ignored in the technical schools, and which, while seemingly non-essential to instruction in current practice and the theory upon which it is based, is fundamental in the broad scheme of engineering education.

"The theory and, later, a little of the practice of an important branch of engineering is now presented to the student with little or no introduction; that is, he begins to study the subject in the present, and practically ignores the previous stages of its development. Verily the last comes first.

"This procedure leads to a groping habit of mind. The student vaguely wonders about the earlier steps in the development of the subject in hand, but finds his time well filled, and leaves investigation to the leisure of his later years; and, if he be successful, he rarely finds that leisure available for the work.

"The study of the history of engineering, be it ever so brief and incomplete, will lead to the investigation of the work of other engineers and often, in consequence, to the avoidance of error into which others have fallen, and to a great saving of labor in duplicating what has already been well done. Often, too, there will be discovered an excellent foundation for successful work.

"It is manifestly impossible to go deeply into the history of any subject; its proper presentation often requires more time than is now available; but a brief and well-presented introduction would add greatly to the student's interest and zest, and would inform him where to find the material for, and impress upon him the value of a thorough knowledge of the various steps in the development of the subject under consideration. In rare instances such an introduction is presented in the text-book. The first chapter in Dugald Clerk's volume on 'The Gas and Oil Engine' is an historical sketch derived largely from the patents issued upon gas motors by various countries. But such a plan is not feasible, because a number of different text-books will always be used, and to preface each with a history of the subject would be to multiply greatly the labor and expense of producing the book.

"It would be best, in the writer's opinion, to produce not a single volume or work embracing the history of all engineering, but a number of monographs, each devoted to only one subject. The publication of the English Men of Letters and the American Statesmen Series indicates how successfully the work might be carried out. This plan would make portions of the work available within a very short time, for there are undoubtedly members of the Society who are prepared to produce at once monographs on the subject of their particular interest; it would not draw heavily upon the Society's resources, and it would allow time for thorough treatment of the more important subjects. A history of each subject, so brief that it would read like the generations of Noah, would produce a volume so large that it is not to be considered. The previously mentioned introduction to Dugald Clerk's 'The Gas and Oil Engine' is little more than a catalogue of patents, but it occupies twenty-eight pages of good size. Yet the subject is simple, indeed, in comparison with bridges, the steam-engine, the electric generator and motor, or ship-building.

"Again, in the production of a work of encyclopedic character, the writer's individuality is lost, whereas in the monograph bearing the name of the writer, there is every incentive to work of the highest order. Hence it is probable that separate treatment of the various subjects would produce results much more satisfactory to the writers, to the students, and to the Society, and much more beneficial to the cause of engineering education."

E. J. McCaustland.—"Mr. Waddell's paper advocates two very distinct propositions—one of these the writer regards as of very doubtful value, but with the other he most heartily agrees.

"First, as to the advisability of instructing engineering students in the history of the engineering profession. The author has pointed out one of the chief objections to the technical schools taking up this work, viz., lack of time. This objection however can not be disposed of by saying that it is a lame excuse and that the remedy is to increase the time, or that something of less importance should be left out. We are rightfully calling for a broader education of the engineer; for a widening of his horizon beyond the purely technical field of his profession; for a training that shall arouse his sympathies for humanity, quicken his impulses for good, and prepare him to be a leader of men.

"The chief obstacle which lies in the way of fulfilling these needs is the lack of time which young men give to college work, and the practical impossibility of requiring them to devote more time in the present stage of the growth of engineering education. In this time, the purely technical has crowded out all else, and still clamors for more space. The proposition with which we are confronted then, is this: With no increase of time in view, and the schedules already full to overflowing with technical subjects, is there anything that could wisely be omitted in order to make room for the history of engineering? Mathematics, physics, chemistry, geology, mechanics and hydraulics, surveying, bridges, railroads, sanitation, engineering jurisprudence, steam and electrical machinery, etc., all crowded into a short term of four years are fundamental in an engineering course. No one of these is of less importance to the student of engineering than the history of his profession, and hence we have no justification in cutting out any one of them.

"The alternative would be to increase the time. But with increase of time come demands for a place in the curriculum from other subjects which the writer believes to be of vastly more importance than the history of engineering. The necessity for more extended and more careful training in English is being forced upon us, and this training should, to a very great extent, precede all technical work. No student should be allowed to enter technical classes, who lacks the ability to express his thought on the written page in simple, but correct and concise language. Is there any question as to the comparative value to the student, of a thorough knowledge, and facility in the use of his mother tongue, and a like knowledge of the history of the engineering profession? If a place can be made for it in the curricula, let us have further training in English. Even when this is accomplished, there is still political science, general history, current history, philosophy, or public speaking, any one of which will do more to broaden and develop the young student of engineering than would the study of the history of engineering. Engineers, as a whole, are no more narrow in their views of life, its privileges, and its obligations, than are the members of the other learned professions; nor are they any more likely to confine their whole interests within the restricted boundary of their own work. Their field is as wide, or wider, than that of law, medicine, or theology. But the great work-a-day world, strenuous and self-centered, is more generally affected by questions of law, of medicine, or of theology than by questions of engineering, and hence the engineer is somewhat restricted in the field in which his efforts receive recognition. But this very fact should force upon the attention of engineering educators the necessity of training their students to be essentially men of their times, or in advance of their times. This can not be accomplished unless his education takes him beyond the field of technical work and opens his mind and heart to the ideas and ideals which are moving forces in the minds and hearts of millions of his fellow beings.

"One other objection to the teaching of the history of engineering is noted by the author, that, he suggests, might be met by the compilation of a proper text. It occurs to the writer that very few professors in the technical schools could teach the history of engineering, no matter how suitable the text might be. To teach history of any sort well requires a great degree of enthusiasm on the part of the instructor, and a like degree of interest on the part of the student. Unless the student had interest and enthusiasm, the professors are few who would have the ability to inspire these feelings in him. If he had this interest and enthusiasm, a well-written text would suffice for his needs and he would get great good from its perusal.

"Here, the writer thinks, is the justification for Mr. Waddell's suggestion. We should have such a history as a record of past achievement in a growing profession, to interest and inspire both young and old, but such history has no place in the curricula of the modern schools of engineering. It follows, therefore, that with the main proposition of Mr. Waddell's paper the writer is most heartily in accord. There is a definite and growing need for such a history as he outlines in his paper, and this Society is in a position to undertake its compilation and publication with every promise of success. The suggestions offered by the author are, in the main, very good, and the writer is in favor of the appointment of a committee for the purpose indicated."

Mr. Williston.—He thought the Society very nearly of a mind that it is exceedingly desirable that there should be more literature on the subject. He thought it also an exceedingly difficult task, and probably one which is not practical, in the way in which it is suggested, yet there are possibilities that something tending in this direction might be accomplished through arrangement with some engineering publishing companies, for example, with the Engineering News, with which the Society has an arrangement for its publications. Papers on historical subjects connected with engineering might be encouraged for the annual meetings. He thought a long discussion of the subject at that time not desired and moved that the president appoint a committee of three to find out and report if there is anything that can be done in this direction.

Professor Jackson.—It is all right to teach engineering history, where it can be done suitably; it is an important subject, which every engineering teacher teaches more or less. Probably there is not a single one who does not have some fair idea of the history of the professions. He wished further to say that the engineering men who are out in practical life seem to have a kind of instinctive notion that they not only know how to build bridges, and do their professional work, but they know how to teach the professional student, and the college professor who has made that his life work.

Professor Woodward.—The motion is that the president appoint a committee of three to consider and report if anything can be done in this direction. Is there a second?

Professor Raymond.—He seconded the motion, if for nothing else than out of respect for the work that Mr. Waddell had done in this matter, which he thought deserved that attention. The gist of all the discussion is that the history of engineering is a desirable thing. Whether there should be one or a dozen volumes is not clear; some think there should, and some do not. It seems entirely desirable that such a committee at least consider the matter and report back to the Society the following year.

Motion carried unanimously.

The president appointed two members on that committee, at once, Professor Williston and Professor Raymond; subsequently he added Professor Merriman.

GENERAL SPECIFICATIONS

FOR

HIGHWAY BRIDGES

OF

IRON AND STEEL.

INTRODUCTORY NOTES.

This pamphlet was written and published by Dr. Waddell in 1888, and, later, was read to the Engineers' Club of Kansas City and submitted to the Associated Engineering Societies for discussion. A second edition, containing discussions by a number of prominent bridge engineers and contractors, was issued in 1889. The Engineers' Club of Kansas City used the pamphlet as the basis for an endeavor to obtain legislation which would regulate the design and construction of highway bridges in Missouri; but opposing interests were more powerful than the Engineers' Club, consequently, the regulating bill failed to pass and the matter was dropped.

The pamphlet was widely used for many years by city engineers and others who desired better structures than the highway bridge contractors were accustomed to offer, but it produced no serious impression upon bridge construction. Bridges built in accord with the specifications were much better and more expensive than those commonly demanded by county or town commissioners. The "highwaymen," as Dr. Waddell dubs the highway bridge builders, found it to their advantage to satisfy the demand for cheap structures; consequently, in the smaller towns and the country districts of most States, bridges are still being contracted for and built much after the manner Dr. Waddell has described in this pamphlet.

De Pontibus was published in 1898, and, as it contains modern and very complete specifications for steel highway bridges, the pamphlet was then withdrawn from sale. The specifications contained in the monograph were of the highest type when they were written, but the use of steel has become universal and the art of designing has advanced; consequently, the specifications are not reprinted herein. However, they contain the foundation for the thorough and elaborate specifications for modern highway bridges which appear in De Pontibus, though several of the features tolerated or even advocated in the pamphlet are repudiated in the later book.

The remainder of the pamphlet, though, is as interesting and pertinent as ever, for the improvement in the methods of contracting for and building the smaller highway bridges is comparatively small. The ignorance, sometimes the dishonesty, of county and town officials, their false ideas of economy, and the unscrupulousness of the average highway bridge contractor keep the system in vogue. Of all branches of public business, bridge construction is the most notoriously ill-conducted. Dishonesty on the part of the contractors and the public officers is exceedingly common. The action of New York and Colorado, in placing the design and construction of such structures under the supervision and control of the State Engineer,

lends countenance to the hope that the day is not far distant when t
methods of purchase and the supervision of the design of ordinary highw
bridges will be universally under the control of competent engineers. Un
then the waste of public moneys, the corruption of contractors and min
officials, and the menace to public safety attendant upon ill-designed a
ill-constructed highway bridges must continue.

Public abuses are generally corrected slowly, but when scientific know
edge is requisite to a clear understanding of the case, it seems impossil
to arouse public interest, as it is necessary to do if corrective laws are to
enacted. Consequently, the growth of law compelling the proper desi
and construction of bridges is exceedingly slow. Little improvement is
be expected until the State or the County employs competent engineers
design bridges or to prepare specifications and pass upon the designs offer
by the bridge builders. No board of freeholders, trustees, or county co
missioners selected from the business men of the community is qualified
determine the merits of the various designs offered, and as the sizes a
thicknesses of metal are often omitted from the drawings, the character
the structure is fixed entirely by the contractor. Cheap and faulty detaili
may double the stresses in the members, yet they will be passed witho
criticism by any one but a trained engineer.

When laymen are both judge and jury, it becomes necessary for t
bridge contractor to send a representative to explain what he is offerin
The representative attends ten lettings for every contract obtained; cons
quently, in purchasing a bridge the town or county pays the expenses
every contractor's representative attending the letting and the cost of eve
set of plans presented. If a competent engineer retained to design t
bridge in question, or regularly in the employ of the State, were to prepa
plans and specifications, bids would be sent by mail and a good structure
the least reasonable cost would be assured. The so-called competiti
system now so generally in vogue compels the contractors to combine a
put up prices or go out of business, and permits the forensic skill or t
trickery of the salesman rather than the price and the merits of the desi
to win.

Though highway bridge design has improved somewhat, failures a
still frequent, and the annual loss of life and property is by no means inco
siderable. The greatest improvements have been effected in the large citi
and in the states which employ competent engineers, but the great bulk
the smaller structures are still badly designed and ill-constructed at gre
expense to the tax-payer. "The mills of the gods grind slowly," but it
to be hoped that the day of better things is closer than it appears to be.

The Association of Highway Bridge Builders proposed by Dr. Waddell
not to be considered beneficial, for in the first place it is illegal, sin
it would act to restrain competition; and, again, such associations soon

or later take on a questionable character and fail in their original purpose. The action of the outsider compels the adoption of more or less dishonest methods, then the purchaser suffers. The reform must result from a revision of the laws governing the purchase of bridges, for collusion and unfair combinations will exist while the placing of contracts is in the hands of incompetent parties.

GENERAL SPECIFICATIONS
FOR
HIGHWAY BRIDGES
OF
IRON AND STEEL.

CONTENTS.

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* N. B.—The specifications have been omitted in this compilation owing to their **antiquated** character and to the fact that up-to-date highway bridge specifications are given in Dr. **Waddell's** De Pontibus.

PREFACE.

In presenting the second edition of this little work to the public, it appears to the author advisable to preface it with a few words explanatory of its object and indicating the results which the first edition has accomplished, also those which the author hopes that the treatise will eventually effect.

The sole object of the pamphlet is to bring about a much needed reform in the present methods of designing, letting, and manufacturing highway bridges.

In order to see whether it be possible to reach county commissioners and produce any impression upon them, the author obtained the endorsements of a number of the leading engineers of America for his pamphlet, then had them printed and circulated among county commissioners, but the effect has proved to be almost *nil.* It is useless to try to accomplish any reform through men who are entirely ignorant of the first principles of bridge designing, and even of the necessity of having perfectly safe structures.

In another direction, however, the pamphlet has met with better success. The Engineers' Club of Kansas City has taken the matter in hand, and has induced a number of other local engineering societies to join in procuring legislative action that will make the building of safe structures compulsory. The following resolutions were proposed by Mr. Octave Chanute and adopted by the Engineers' Club of Kansas City:

"RESOLVED, 1st. That a committee of three members be appointed by the President to prepare and submit to this Club a form of memorial to the Legislature of this State, together with the draft of a law inaugurating a proper inspection of bridges, and for this purpose the committee may consult with public spirited counsel but without incurring expense except by special authority of the Executive Committee."

"2d. That the Secretary be instructed to notify other engineering societies and clubs throughout this country of the action taken by this Club, and to solicit their co-operation in this movement."

"3d. That in case of the appointment of similar committees by other societies, the Committee of this Club be instructed to confer and to co-operate with them in drafting the project for the proposed law, and in drawing up general specifications and rules to guide the State Inspector."

The Engineers' Club of Kansas City also obtained a general discussion upon the first edition of the pamphlet by a number of prominent engineers and bridge builders, which discussion was published in full in the Journal of the Association of Engineering Societies for November, 1888. A larg portion of it is given in Chapter IX.

In preparing this new edition the author has availed himself of th criticisms and suggestions of these gentlemen, so as to improve his specif cations in a few particulars. The principal changes will be found in th clauses relating to " Limiting Lengths of Span for Different Perpendicula Distances Between Central Planes of Trusses," " Vertical Sway Bracing, " Top Chord and Batter Brace Sections," " Working Tensile Stresses (for steel), and " Bearings upon Masonry."

In respect to the last paragraph of Chapter I., the author would stat that thus far his professional duties have occupied so much of his tim that he has been unable to prepare the diagrams referred to. Howeve he hopes that within a year he will be able to find sufficient leisure to mak the necessary calculations.

The Committee of the Engineers' Club of Kansas City upon " Highwa Bridge Reform " last winter drafted a law and memorial to submit to th Legislature of the State of Missouri. Copies of these were sent to th various local engineering societies throughout the country, and the pro posed law was published in some of the engineering papers. It is hope that this draft may serve as a basis for similar laws in other States. C course it will always require some modification for any particular case. I was unfortunately found necessary to modify it fundamentally in sul mitting it to the Missouri Legislature, owing to the opposition develope Moreover, it was not considered advisable to press the bill this year, bu to let it lie over till the next session of the Legislature, when its frienc will renew the attack with increased vigor. If such a law as this b passed in a number of states, the next step to take will be to have a cor vention composed of bridge engineers and a representative from eac local engineering society for the purpose of deciding upon standar specifications for highway bridges.

J. A. L. W.

KANSAS CITY, MO., June 1, 1889.

GENERAL SPECIFICATIONS FOR HIGHWAY BRIDGES OF IRON AND STEEL.

CHAPTER I.

INTRODUCTION.

That there is urgent need for reform in the methods of designing highway bridges, especially in the West, no one who is at all familiar with this class of structures is likely to deny; and any one, no matter how ignorant he may be upon the subject, who will read the contents of the next chapter, will readily be convinced that the time has arrived to put a stop to the building of such death-traps as there described. It is easy to say that the time has come to accomplish this end, but it is an entirely different matter to effect even a beginning. Within the last ten years several attempts have been made to improve in various ways the methods of bridge designing and to open the eyes of the public to the fact that their lives are in imminent danger whenever they pass over certain important structures; but without avail. The iron bridges built to-day in the West are often more unsafe than those built five years ago. In a country so progressive as the United States of America such retrogression is abnormal. One is immediately inclined to ask, "What can be the cause or causes?"

They are, first, indifference and a lack of knowledge on the part of the people, and second, unscrupulousness and gross ignorance on the part of the majority of highway bridge builders.

To accomplish the desired reform it will then be necessary to awaken the people to a sense of their danger, overcoming their indifference, and show them how they can insure the requisite strength and capacity of future bridges; and at the same time, furnish the bridge builders with rules for design that will enable them to build good, substantial structures at the minimum cost, and prove to them the truth of the old adage that "honesty is the best policy." Such, in short, is the object of this little treatise. How it will fare it is difficult to foretell. The author dares not anticipate any marked immediate success, for this is by no means his first attempt to institute such a reform. However, the circumstances under which this work will be issued are far more favorable than in the previous cases.

There is no doubt that it will meet with much opposition from many highway bridge builders, especially from those whose main object is to obtain the maximum amount of money for the minimum amount of bridge.

Such opposition will be made very quietly, because the reasonin employed will not bear criticism. Moreover, it will do no one any harn except those who will be thereby won over and persuaded that the ol styles of bridges are good enough because they generally manage to stan up under the loads to which they are subjected. This is the favorite argument employed by bridgemen, and a more specious one could not b invented. Bridges will stand for years with the metal strained often fa beyond the elastic limit, waiting quietly for the particular loads which wi accomplish their downfall. Such structures are by no means rare, and ar often to be found on important thoroughfares of large cities. For instanc there is an old iron bridge at the foot of Walnut Street in Des Moine Iowa, crossing the Des Moines River. It seems to have been waitin years for a crowd large enough to make a respectable catastrophe.

There are two bridges in Council Bluffs, Iowa, that are not only disgrace to the city, but are also a source of danger—one of them is bui essentially of gas-pipe,* the other was made by an Iowa blacksmith i his shop. It shows very clearly by unfilled rivet holes, etc., that this wa his first attempt at bridge building.

A prominent Massachusetts engineer, Prof. George L. Vose, write to the author as follows:

"I examined lately an old wooden bridge across the Kennebec River a Gardiner, Maine, which shows how long some of these infernal traps wi stand up in spite of the rules made and provided for such cases. Thi is an old Howe truss with arches, but as the latter have nothing to res against, they are of no use. . . . Taking a moving load of sixt pounds per square foot and ten pounds for snow and mud, and addin the weight of the bridge, makes the strain per square inch on the end rod 47,800 pounds, and the strain per square inch from the weight of th bridge alone about 18,000 pounds. The braces are but little better.

"This, of course, is only one of a thousand cases just as bad.

"However, as the trap has never tumbled down, popular logic decide that it never will, and the public continues to invite the disaster which i sure to come some day."

The same gentleman in a letter published in the Lewiston *Journa* writes as follows:

"We have an iron bridge over the Androscoggin right in the middl of our village, which will be almost certain to break down if it eve happens to get a large crowd of people on it, and it is in exactly the plac where a crowd would be apt to collect in times of freshets. The joint in that bridge which could at the most safely hold 20,000 pounds, wi be called upon to hold 60,000 pounds with such a load as is liable at an time to come upon it. This bridge was sold to the selectmen and warranted to carry 2,240 pounds per running foot, while it cannot safel

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* This structure has lately been removed and replaced by a better one—Jun 1889.

hold over one-fourth part of that load. The company that made that bridge would not dare to submit a plan of it to any competent engineer or inspector, but they do not hesitate to sell it to a board of selectmen, who, not being expert in such matters, would not notice the wretchedly unsafe character of the bridge."

Such instances could be multiplied almost indefinitely, but space will not permit.

How few people there are who have an adequate idea of the importance of the subject of bridge building! People in general seem to have far more faith in bridge builders than in any other members of the community, for they entrust to them daily not only their own lives, but also the lives of others who are near and dear to them. How misplaced is this confidence, as far as integrity is concerned, it does not behoove the author to state, but concerning the technical ability of the average highway bridge builder he feels at liberty to express his opinion.

In this country of universal liberty anyone at all is allowed to build bridges, no matter how ignorant he may be of even the first principles of design, consequently we find men attending bridge lettings and submitting designs who are incapable of calculating the simplest stresses in a structure. As they have no office expenses worth mentioning, by bidding low they manage to obtain contracts, then put up the lightest and cheapest structure that the commissioners will accept, and as commissioners in general know little, if anything, about bridges, the country is in this way strewn with structures that render the traveler's life unsafe.

What remedy is there for this state of affairs? There are several, but the difficulties attendant on putting some of them into practice are at present, perhaps, insurmountable.

First, if there were a State Inspector of Highway Bridges appointed, nominally by the Governor, but in reality by a standing committee of the American Society of Civil Engineers, and if he were given full power to condemn and prohibit travel on any highway bridge, also to say what structures shall and what shall not be built, the desired end would be attained. This would be the best possible way, but the American people are averse to having government officers appointed, preferring the system of election. There are two reasons why the latter would not work in this case: first, because the mass of the people know nothing about the technical ability of the candidates, and second, no specialist of good standing would be willing to put himself in the power of the popular vote.

That this method of appointing State inspectors will be adopted sooner or later, the author is firmly convinced, but the time is not yet; the masses have first to be educated to a sense of their danger, then taught that bridge building is work that should be undertaken by trained specialists only.

Another method of effecting the necessary improvements in future bridges is the formation of an association of highway bridge builders as outlined in Chapter VI., but the author fears that the greed of gain has too firm a hold upon the majority of these parties to permit of their combining, even when the result would be mutually beneficial to the manufacturers and the purchasers of bridges. Some five or six years ago the author endeavored to organize such an association with the object of adopting standard specifications for highway bridges; but it very soon degenerated into an ordinary pool, which, after a year's existence, broke up on account of the bad faith of some of the members. The objects of that association were outlined in a paper entitled "A Proposed Association of Western Highway Bridge Builders," published in *Van Nostrand's Engineering Magazine,* of January, 1882.

This paper will be reproduced in Chapter VI.

Another, and probably the surest way of all to effect a reform in the designing of future bridges would be for supervisors and others who let bridge contracts, to call for *mailed* bids upon structures designed in strict accordance with the specifications in Chapter VII. of this work, filling out for their printed notice the list of data there indicated, and submitting the papers of all the competitors, after the bids are opened by the Board and the amount of each tender noted, to a competent specialist who would decide which designs are in accord with the specifications and which are not, also which is the best bridge for the money. In the notice to bridge builders it would be well to state that, if, upon careful measurement of the ironwork with calipers by an expert, it be found that the sections are scant or that the work is "scamped" in any way, the supervisors may reject any or all of the ironwork or may retain permanently a certain percentage of the price of the structure. This would prevent most effectually what is popularly known as "skinning the bridge."

An equally effective way would be to have complete plans and specifications prepared by a specialist, and submit a copy of them to any legitimate contractor who might desire to bid on the work. The extra expense involved by this method would be offset by the saving in time and traveling expenses of bidders, which eventually must be paid by the public.

Bridgemen will undoubtedly make it a point to tell commissioners that the specifications of this treatise are altogether too elaborate and involve the use of more metal than is necessary for county bridges. Such is not the case. Structures designed according to these specifications will be as light as is consistent with legitimate practice; for in preparing them the author has kept constantly in mind that, next to requisite strength and rigidity, economy is the great *desideratum.*

The author expects his motives in writing this treatise to be maligned, consequently he would ask each one interested in the subject to read over, if not the whole work, at least those portions of it which he can readily understand, before coming to any decision.

If this attempt at reform in bridge design meet with success, the author purposes supplementing it some time in the near future by diagrams giving the weights of iron for highway bridges to cover all cases that will be likely to occur in an engineer's practice, the bridges being designed according to the specifications of this treatise.

CHAPTER II.

HIGHWAY BRIDGE FAILURES.

The subject of this chapter having been made a special study for many years by Prof. George L. Vose, the author can do no better than to quote from that gentleman's forcibly-written paper on "Bridge Disasters in America" practically all that relates to highway bridges, and to supplement it by other statistics, in compiling which valuable aid has been received from Prof. Vose and a few other members of the profession.

The quotations just mentioned are the following:

"Nearly all the disasters which occur from the breaking down of bridges are caused by defects which would be easily detected by an efficient system of inspection. Not less than forty bridges fall in the United States every year. No system of public inspection or control at present existing has been able to detect in advance the defects in these structures, or to prevent the disasters. After a defective bridge falls, it is, in nearly every case, easy to see why it did so. It would be just about as easy, in most cases, to tell in advance that such a structure would fall if it ever happened to be heavily loaded. Hundreds of bridges are to-day standing in this country simply because they never happen to have received the load which is at any time liable to come upon them.

"A few years ago an iron highway bridge at Dixon, Ill., fell, while a crowd was upon it, and killed sixty persons. The briefest inspection of that bridge by any competent engineer would have been sure to condemn it. . . . There are hundreds of highway bridges now in daily use which are in no way safer than the bridge at Dixon was, and which would certainly be condemned by five minutes of competent and honest inspection. More than that, many of them have already been condemned as unfit for public use, but yet are allowed to remain, and invite the disaster which is sure to come. Can nothing be done to prevent this reckless and wicked waste of human life? Can we not have some system of public control of public works which shall secure the public safety? The answer to this question will be, not until the public is a good deal more enlightened upon these matters than it is now. . . . In a country where government controls all matters on which public safety depends, and where no bridge over which the public is to pass is allowed to be built except after the plans have been approved by competent authority, where no work can be executed except under the rigid inspection of the best experts, nor opened to the public until it has been officially tested and accepted, it makes little or no difference whether the public is informed, or not, upon these matters; but in a country like the United States, where any man may at any time open a shop for the manufacture of bridges, whether he knows anything about the business, or not, and is at liberty to use cheap and insufficient material, and where public officers are always to be found ready to buy such bridges, simply because the first cost is low, and to place them in the public ways, it makes a good deal of difference. There is at present in this country absolutely no law, no control, no inspection, which can prevent the building and the use of unsafe bridges; and there never will be until the people who make the laws see the need of such control. . . . As usual, however, in such cases, unprincipled adventurers are not wanting, who, taking advantage of a great demand, do not hesitate to fit up cheap shops, to buy poor material, and to flood the market with a class of bridges, made with a single object in view, viz.: to sell, relying upon the ignorance—or something worse—of public officials for custom. Not a year passes in which some of these wretched traps do not tumble down, and cause a greater or less loss of life, and at the same time, with uninformed people, throw discredit on the whole modern system of bridge building. This evil affects particularly highway bridges. The ordinary county commissioner or selectman considers himself amply competent to contract for a bridge of wood or iron, though he may never have given a single day of thought to the matter before his appointment to office. The result is, that we see all over the country a great number of highway bridges which have been sold by dishonest builders to ignorant officials, and which are on the eve of falling, and await only an extra large crowd of people, a company of soldiers, a procession, or something of the sort, to break down.

" Not many years ago, a new highway bridge of iron was to be made over one of the principal rivers in New England. The county commissioners desired a well-known engineer, especially noted as a bridge builder, to superintend the work, in order to see that it was properly executed. The engineer, after inspection of the plans, told the commissioners plainly that the design was defective, and would not make a safe bridge; and that, unless it was materially changed, he would have nothing to do with it. The bridge, however, was a cheap one, and, as such, commended itself to the commissioners, who proceeded to have it erected according to the original plan; and these same commissioners now point to that bridge, which has not yet fallen, but which is liable to do so at any time, as a complete vindication of their judgment, so called, as opposed to that of the engineer who had spent his life in building bridges. . . . We often hear it argued that a bridge must be safe, since it has been submitted to a heavy load, and did not break down. Such a test means absolutely nothing. It does not even show that the bridge will bear the same load again, much less does it show that it has the proper margin for safety. It simply shows that it did not break down at that time. Every rotten, worn out, and defective bridge that ever fell has been submitted to exactly that test. More than this, it has repeatedly happened that a heavy train has passed over a bridge in apparent safety, while a much lighter one passing directly afterward has gone through. In almost all such cases, the structure has been weak and defective; and finally some heavy load passes over, and cripples the bridge, so that the next load produces a disaster.

"For the test of a bridge to be in any way satisfactory, we must know just what effect such test has had upon the structure. We do not find this out by simply standing near, and noting that the bridge did not break down. We must satisfy ourselves beyond all question that no part has been overstrained. . . . There are several concerns in the United States which make a specialty of highway bridges, and which, taking advantage of the ignorance of public officials, are flooding the country with bridges no better than that at Groveland.* On an average at least twenty of these miserable traps tumble down every year, and nothing is done to bring the guilty parties to punishment. Dishonest builders cheat ignorant officials, and the public suffers the damage and pays the bills.

"Is human life worth enough to pay for having these structures inspected, and, if found unsafe, strengthened or removed? Can we do anything to prevent towns and counties from being imposed upon by dishonest builders? We certainly can, if those who control these matters care enough about it to do it. There are two ways of buying a bridge,—a good way and a bad one; and these two ways are so plain that no one can misunderstand.

"To buy a bad bridge just as soon as your town or county votes money for a new bridge, certain agents—and they are as numerous as the agents for sewing machines, or lightning rods—will call on, or write to, the town or county officers, and will offer to build anything under heavens you want, of any size, shape or material, and for almost any price. They will produce testimonials from all the town and county officers in the country for the excellence of their bridges, and would not hesitate to give reference, even for their moral character, if you should ask it. If they find that you don't know anything about bridges, they will, to save you the trouble, furnish a printed specification; which document will commit you to pay the money, but will not commit the bridge company to do anything at all. When the bridge is put up, you never will know whether the iron is good or bad, nor whether the dimensions and proportions are such as to be safe or not. You will know that you have paid your money away, but you will never know what you have got for it until some day when your bridge gets a crowd upon it, and breaks down, and you have the damage to pay. This mode of buying a bridge is very common.

"To buy a good bridge, first determine precisely what you want; and if you don't know anything in regard to bridge building yourself, employ an engineer who does, to make a specification stating exactly what you want, and what you mean to have. Then advertise for bridge builders

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* The bridge referred to was built in 1871-1872, across the Merrimac River, at Groveland, Mass., a few miles below Haverhill. One span broke down in January, 1881, under the load of a single team and small amount of snow.

The bridge could not carry safely a load exceeding one quarter of that which it was warranted to carry by the manufacturers.

to send in plans and proposals. Let the contractors understand that all plans and computations are to be submitted to your engineer, that all materials and workmanship will be submitted to your inspectors, and that the whole structure is to be made subject to the supervision of a competent engineer, and accepted by him for you. You will find at once that, under such conditions, all traveling agents and builders of cheap bridges will avoid you as a thief does the light of day. You will have genuine proposals from responsible companies, and their bids should be submitted to your engineer. When you have made your choice, let the contract be written by your lawyer, and have the plans and specifications attached.

"Employ a competent engineer to inspect the work as it goes on; and when it is done, you will have a bridge which will be warranted absolutely sound by the best authority. This mode of buying a bridge is very uncommon. . . . . One point always brought forward when an iron bridge breaks down, is the supposed deterioration of iron under repeated straining; and we are gravely told that after a while all iron loses its fiber, and becomes crystalline. This is one of the "mysteries" which some persons conjure up at tolerably regular intervals to cover their ignorance. It is perfectly well known by engineers the world over, that with good iron properly used, nothing of the kind ever takes place. This matter used to be a favorite bone of contention among engineers, but it has long since been laid upon the shelf. No engineer at the present day ever thinks of it. We have only to allow the proper margin for safety, as our first-class builders all do, and this antiquated objection at once vanishes. The examples of the long duration of iron in large bridges are numerous and conclusive. . . . . It is impossible to say how many highway bridges have broken down during the past ten years, but it is estimated by bridge builders that the number can not be less than two hundred. This is, no doubt, far within the truth; and by far the larger part of these structures are not old wooden bridges, but are new bridges of iron."

The following statistics have been furnished by Prof. Vose and others.

In 1876 a bridge at Vallonia fell down with no load on it.

In February, 1876, an iron bridge across the canal at Lafayette, Ind., fell down with thirty head of cattle on it.

A bridge at Reynoldsville, Pa., fell in February, 1876, the only load on it at the time being some mud.

A bridge at Guadaloupe, Texas, fell in the winter of 1875-1876 under no load but its own weight.

In 1871 a bridge fell, soon after completion, near Bloomington, Ill. One near Oskaloosa, Iowa, fell under ordinary road travel. One in Lebanon County, Pa., also fell. A span at Napoleon, Ohio, fell, killing a man and some cattle. One at Sharon, Pa., tumbled into the canal in less than thirty days after completion. One at Bucyrus, Ohio, failed without any apparent cause. One at Lancaster, Ohio, fell with about twenty head of cattle.

In *Engineering News* of August 20, 1887, there appeared the following letter:

"WABASH, IND., August 9, 1887.

"EDITOR ENGINEERING NEWS:

"We had the misfortune to meet with a bridge disaster in our city last evening. A traction engine fell through a bridge into the canal, killing one man and injuring one.

"I was called upon to investigate the matter (after the accident, of course), and was horrified to find a pine floor-beam 6 x 12 inches, carrying (endeavoring to carry) a panel 12 feet long and 16 foot roadway.

"This was well rotted off, and, of course, simply crushed down. It was built, I learn, by a '*practical bridge man*' off a big railroad—and away off. . . .

"Respectfully, F. KNIGHT."

In the early part of this year (1887) a 160-foot iron arch span near Animosa, Jones County, Iowa, failed under a herd of cattle. The cause of the failure was never investigated, but it is stated upon good authority that it was weakness in details.

Some two or three years ago a wooden bridge newly built by local contractors in Mills County, Iowa, gave way under a passing wagon, crippling several of the occupants.

On September 13, 1887, at Centropolis, Kansas, a bridge over a creek broke down under a road scraper drawn by six horses. Six men were injured, one of them fatally. (*Vide Engineering News,* p. 233.)

On July 4, 1882, a small wooden bridge failed under a load of a single wagon. One woman was fatally injured, but the other eight occupants of the vehicle escaped unharmed. The woman's husband recovered $15,000 from the county. The cause of the accident was weakness in the pile substructure.

At Elgin, Kane County, Ill., a Truesdell patent iron bridge fell four months after erection, was replaced, fell again a few months later, again replaced and finally washed out. A pile bridge is now used at that crossing and as it does its work, the popular opinion of the neighborhood is that a wooden bridge is superior to an iron one.

In the same county at Dundee, a team ran away and struck an iron bridge, causing its downfall. The details of these Kane County bridge disasters which were furnished the author are very meagre, consequently he cannot state whether there was any accompanying loss of life.

The following is from a New York paper of January 27, 1888:

A special from Portland, Ore., says: "The large bridge which spans the river at Umatilla was the scene of a miraculous escape from death of over one hundred persons, Wednesday. Men, women, and children had gathered to watch the ice gorge break, when a drove of cattle rushed across the structure. The bridge sank beneath its great burden, and a moment later fell into the swollen stream. Spectators and beasts were hurled in every direction. Six men, three women, and a boy were picked up unconscious and bleeding from numerous wounds. It is thought two of them will die. The rest of the spectators escaped with little injury."

On February 18, 1887, a highway bridge over the Genesee River at Rochester, N. Y., collapsed. The primary cause of the accident was wind pressure upon telegraph poles, which should never have been allowed upon the bridge. The structure, however, was of a very objectionable type, viz., the bowstring; and as there were two sidewalks, the pony trusses were without side bracing.

The following are from *Engineering News:*

On July 25, 1888, a wooden highway bridge across the Patapsco River, Md., gave way under a wagon and team.

On July 26, 1888, a canal bridge near Newark, Ohio, gave way under a wagon and team, and one man was seriously injured.

On August 4, 1888, the stringers of a toll bridge across the St. Croix River at Calais, Maine, gave way under a team, throwing the team and two men into the river.

During the same month a wooden highway bridge over the Netchang River at Chaplin, Conn., collapsed.

On September 19, 1888, a highway bridge over the Quinsigamond River at Grafton, Mass., collapsed.

On February 1, 1888, a girder of the Sixth Street bridge over the Arkansas River at Pueblo, Colo., broke under a load of 20,000 pounds of horse shoes, the bridge settling about four feet.

On April 5, 1888, an iron bridge over New River at Fayette Station, W. Va., built two years previously at a cost of $18,000.00, was "blown down and destroyed."

On May 23, 1888, the highway bridge at Lake Side, near Medina, N. Y., gave way while being repaired. Three men with a team and wagon-load of hay were thrown into the water, but were rescued.

On May 28, 1888, three spans of the bridge across Muskingum River at Gaysport, Ohio, were blown down. The bridge was completed the previous November at a cost of $40,000.00. The three spans wrecked were 140 feet long and cost $7,350.00.

On September 26, 1888, a highway bridge over Rock River, near Janesville, Wis., collapsed.

One of the bridges over the Don River near Toronto, Ont., collapsed recently (November, 1888), under a heavy wagon load of stone. The wagon, men, and horses went down thirty feet into the shallow bed of the river. Nobody was injured.

On November 10, 1888, the highway bridge over East Haverhill Street, at Lawrence, Mass., collapsed. No passengers were on it at the time.

The swing bridge over the canal at Benton Harbor, Mich., broke down recently (January, 1889), under a team with a load of lumber. No one was hurt.

On January 9, 1889, the roadway suspension bridge over the Niagara River, below the falls, was completely wrecked by the wind, only the towers being left standing.

On April 28, 1889, a bridge over an artificial lake at Chelsea Park, Kansas City, gave way under a crowd which had gathered to see a man walk on the water, but no one was killed.

On April 30, 1889, a section of the Oconee River bridge at Milledgeville, Ga., gave way under repair; it had been condemned as unsafe.

On May 11, 1889, a highway bridge, near the depot at Schenevus, N. Y., collapsed under a team with a load of lumber. The driver was seriously injured. The bridge was said to be unsafe, but had not been condemned.

Other instances of highway bridge failures could readily be given; in fact, if one were to set about compiling a list in a systematic manner, and not according to the desultory method pursued by the author, its magnitude would soon become appalling.

CHAPTER III.

BRIDGE LETTINGS.

The ordinary routine of bridge lettings is about as follows:

A month or two before the letting occurs an advertisement is put in a local paper, stating that on such a day at a certain hour bids will be received for one or more bridges. Generally the spans are given, and often the width of roadway, but here the list of data usually ends. Sometimes, though, a fairly complete list is given, enabling contractors to make their designs before visiting the locality where the bridge is to be let.

On the day of the letting, or perhaps a day earlier, from ten to twenty "traveling men," some representing bridge companies, but others merely "scalpers," assemble for the purpose of "putting up a job" on the county by getting as large an amount of money as the commissioners will give in exchange for as light and cheap a bridge as they will accept.

There is usually a secret meeting of the competitors at which it i decided first, " how much the bridge will stand," *i. e.,* what is the greates sum they dare ask; second, what the cheapest acceptable bridge ought t cost; third, who is to have the contract; and, fourth, how the estimate profits are to be divided between the one who takes the contract and hi unsuccessful (?) competitors. If these four points can be settled amicably all goes well, but as there are always wheels within wheels, the meeting not infrequently is dissolved without an understanding being arrived at In this case the competitors "go in on a fight," as they term it, bidding far below the cost of a legitimate structure and often below that of th cheapest bridge they can erect, merely for the sake of spiting some othe bidder. Occasionally two companies get into such a wrangle that thei representatives cannot meet at a letting without causing "a fight." Th formation of a pool may be bad for the county, but " going in on a fight' is much worse. In the first case there is a chance of obtaining a passabl structure, but in the second case there is none whatsoever.

The irresponsible bidders (and their name is legion) present design of the lightest possible description with the full intention of scamping the work in every way that they dare. As the lowest bid is generally accepte (one bridge being as good as another in the eyes of most commissioners) the county is sure of getting a disreputable piece of work.

In certain States, for instance Missouri, the law makes it compulsor that the bridge lettings be done by public outcry. In such cases the *modus operandi* is as follows: The commissioners select the papers of one of the bidders, and upon this basis the bridge is auctioned off to the lowest bidder As far as pooling is concerned, this auction method has no effect either way; but when a fight occurs, the party whose papers are chosen has a decided advantage, which at first thought is not apparent. The explanation, though, is simple, and the scheme, to say the best of it, is quite ingenious. Mr. A. attends the letting with two sets of papers that at first glance appear to be exactly alike. A close inspection, however, would show that they represent two bridges of widely varying weights. In one thick metal is used throughout; in the other the thinnest that can be obtained. Mr. A. gives the *heavy* papers to the commissioners for the crowd to bid upon, and when the auction takes place he bids upon the basis of the weight of the *light* structure, and consequently can afford to go lower than any one else. As soon as possible after the work is knocked down to him by the auctioneer he asks to see the papers and avails himself of the opportunity to effect an exchange.

This plan of exchanging papers is by no means confined to auction lettings; it can be made to work at any kind of a letting.

Sometimes the commissioners have some local engineer, or perhaps a bridge builder, prepare special designs upon which every competitor bids.

Unless the designer take care to specify throughout the thinnest shapes that are rolled, the chances are that the contractor will reduce the weight of the bridge by using them, for the ironwork of highway bridges is very seldom touched with the calipers after it leaves the shop. Not only do some contractors put in lighter sections than are specified, but they also figure upon doing so when making out their estimates of cost.

In general, county commissioners, before inviting tenders, make an appropriation for the work, the amount of which bridgemen make it their business to ascertain. It is seldom, indeed, that the amount is found to be too small to build some kind of a bridge. By shortening the total length, substituting wood for iron, narrowing the roadway, decreasing the live load and increasing the unit stresses, a design can be made to come within the appropriation and still leave a little to divide among the bridgemen. There is no surer means than this of obtaining a dangerous structure.

The question of bribing commissioners need not be entered upon here. That they are pecuniarily persuaded sometimes even the most hardened contractor will not deny; he will merely assert that it was some other man who did the bribing.

From the foregoing it might be supposed that the author is unyieldingly opposed to the pooling system—on the contrary he considers it a necessary evil—what he objects to is that it is carried too far. At first it was used to insure the different bridge companies attending a letting against loss of time and traveling expenses. In this respect it was legitimate; for, if the supervisors insist upon bidders attending lettings in person, it is only right that the former should pay for the pleasure of their company. But finding it so easy to be reimbursed for actual expense, the competitors very soon conceived the idea of making a little profit out of their misfortunes. Traveling men seeing what a profitable business attending bridge lettings had become, began to set up little bridge companies for themselves, thus increasing the number of competitors and filling the country with a crowd of so-called bridge builders, whose offices and shops often consist merely of desk room somewhere, and whose only desire in attending lettings is to extort blackmail. Purchasers of bridges have only themselves to thank for the institution of pooling. Were contractors assured of fair dealing in every case, they would prefer to send their bids by mail, but unfortunately partiality is too often the order of the day, therefore in self-defense they have been forced to pool.

A method of dealing with the pooling question will be outlined in Chapter VI.

The following amusing incident was related at the rooms of the Engineers' Club of Kansas City, after one of the meetings at which the contents of the first edition of this pamphlet were discussed. It was published the next morning in the *Kansas City Journal,* and as it exemplifie very clearly one of the numerous tricks of the trade, it will be reproduce here, notwithstanding its rather inelegant diction:

"A bridge builder was telling me a sort of funny story the other day and I have no doubt similar occurrences often happen. He was dow in Southern Missouri some time ago to bid on a bridge. Of course, h was pooling, or he wouldn't have been there. There were fourteen bidder in the whole crowd, and thirteen of them were to put in bids away u out of sight, while the fourteenth would put in a bid that would be jus low enough to be in sight, get the work, and pay the other thirteen a commission.

"Some one ascertained that the Union Bridge Company, of Buffalo had submitted plans to the commissioners, but had no representative o the ground, and of course the pool was 'busted' unless the Union Company could be floored.

"Now county commissioners don't know a bridge plan from a pictur of Christ before Pilate. They look at them very soberly, and if no on is around who has sense enough to see that they are holding them upsid down, they are quite liable to get a reputation for wisdom.

"We had to down the Union Company or lose our traveling expenses and one of the bidders present said: 'I'll go in and look at those Unio plans and see if I can find anything the matter with them.'

"He went in and expatiated on his own plans; told the county commissioners that all the rest of us were thieves, and then came out and said

"'Boys, those plans are on the table in there, and I can't find a cusse thing the matter with them except that the lower chord of the bridge i made of round iron instead of flat.'

"Well, of course you know that that makes hardly any difference a all about the strength or durability of a bridge. It's just a little unusual that's all, and I suppose that the Union Company would have given fla iron at the same price.

"Then I went in and after telling the commissioners how good was, and how my plans were the greatest effort of my life, I looke around casually and glanced at the Union plans and said: 'Humph That fellow's pretty old fashioned. Uses round iron don't he?'

"Then I went out and the next man went in, and after ten minutes' fre exhibition of the noblest public spirit Missouri ever produced, his ey caught the Union Bridge plans, and he said: 'Well, that fellow is cutting in on his margin of safety. I—should—say. Uses round iron in hi bridge, don't he?'"

"Then the next man stepped up, and after the usual ten minut course in civil engineering furnished free to the commission on accoun of official position, he said, the instant that his roving sight happened t be riveted by the glaring defect in the Union plans:

"'Holy smoke!'"

"'What's the matter?' asked the bridge commissioners.

"'Nothing at all, gentlemen, nothing at all.'

"'Anything wrong with those plans there?'

"'Gentlemen, if there was anything wrong you would have to find it out from somebody besides me,' and he went out.

"After the commissioners had been subjected to ten more such experiences they threw out the Union plans, and there were thirteen commissions paid for one contract."

CHAPTER IV.

HOW BRIDGES ARE BUILT.

In this chapter it is the intention to point out the most common faults and glaring defects that are to be found in nine out of ten of the iron highway bridges which one would cross in a day's ride through any well-to-do county in one of the Western States.

First, we will treat of the data according to which they are designed. If the appropriation be large enough, the live load assumed for making calculations is generally about right, viz., eighty pounds per square foot of floor; but if there be a small appropriation, or if the bidders fail to come to an understanding, it too often happens that the live load is reduced considerably below that amount. It is sometimes made as low as eight hundred and even five hundred pounds per lineal foot of bridge. But even when an amply large live load is used in proportioning the trusses, the floor beams will often figure for hardly half that load. This is due not to ignorance, but to dishonesty. It would be far better to put the heavy load on the floor system and the light one on the trusses, for the former is liable to receive its full load often, but the latter seldom, if ever.

Joists are often made too light, and although the danger of their breaking is not great, they spring to such an extent as to set up vibrations that are injurious to all the principal parts of the structure. Light floor beams produce the same effect. That rigidity in a structure is just as important as strength is a principle which highway bridge builders generally appear to ignore. In most bridges there are too many loose joints and connections. For instance, floor beams are suspended from the bottom chord pins by adjustable hangers, and nothing is done to stay them, either laterally or longitudinally, hence when the lateral rods are attached to them, as is usually the case, the whole lower lateral system, if it can be termed a system, fails to act with the chords; consequently, the lightest lateral rods used will be just as efficient as the strongest. Again, the upper lateral struts are often simply screwed up against the chord pins, making a loose and inefficient connection.

Then, the portal bracing is almost without exception proportioned simply by guesswork, and consequently has far less capacity than that called for by the proper calculations.

The subject of rigidity brings up another point, viz., the use of improper styles of truss, merely for the sake of saving a little metal. This is exemplified by the numerous arches and parabolic trusses one finds almost everywhere. Such structures can not be thoroughly braced laterally so as to resist wind pressure and vibration from passing loads.

In this connection it would be well to point out that the double intersection or Whipple truss is often used for short, narrow spans, rendering the sections of main members so small that the structures vibrate in a manner which must be very injurious to the metal. Again, pony trusses are often built without side-bracing of any kind, and the top chords are proportioned for single panel lengths. What the actual intensities of stress are in these members no one at present can say. To obtain some idea of their magnitude it would be necessary to load several of these pony truss bridges until they break, taking care to apply the loads with the same amount of impact which would be likely to come upon them in ordinary use.

Still another way in which rigidity is neglected is by building long spans with narrow roadways.

The common practice of making hip verticals of bars or rods instead of channels, although it is the custom of many good bridge companies, is not conducive to rigidity.

The use of very light rods for counters and laterals, simply because the calculated stresses do not call for greater sections, causes vibration and consequently wear on the metal that, in most cases, would be overstrained by the live loads statically applied. The use of long, narrow posts, whose ratio of length to least diameter far exceeds the limits of good practice, is also a great cause of vibration.

Next come the considerations that affect the strength as well as the rigidity. Among the most important are the following:

Failing to stiffen the bottom chords in end panels of light, narrow, and deep-trussed bridges, thus rendering most of the metal employed to resist wind pressure practically useless; failing to pay attention to what may be termed induced stresses, or stresses caused indirectly by wind and other loads; the use of iron so thin that it is liable quickly to rust out or that will buckle under stress without developing the full strength of the member. This is a most common fault; for iron 3-16 inch in thickness will be found in many bridges, while the proper limit is ¼ inch; and ¼ inch cover plates are used for top chords and batter braces up to twenty inches width and even more, while the strict rule of design would limit the width to twelve or thirteen inches.

Scamped details in highway bridges are the rule, not the exception. One seldom finds sufficient rivets in splice plates, reinforcing plates, etc., and lacing bars are nearly always too light and have too much spread—in fact they are sometimes omitted altogether and replaced by stay plates with a single rivet at each end, spaced from three to six feet apart.

Short stay plates at the ends of systems of lacing, rollers smaller than permissible, insufficient pin-bearings, overstrained pins, badly stayed hand-railings, unstiffened webs in floor beams, absence of anchorage of trusses to piers and abutments, long rods not upset, inefficient extension plates on posts, inefficient chord splices with a single row of rivets on each side of the joint, the use of rivets of too small diameter, rivet spacing longer than is allowable, improper use of cast iron, fish-bellied girders with web-section insufficient for the shear, and, worse than all these, rivets used in direct tension, are features that are altogether too common in highway bridges.

The employment of gas-pipe for struts, and resting joists on chord bars are almost things of the past, yet one does come upon them occasionally in designs for new bridges.

Bent eyes on lateral rods and double beam hangers without any means of equally distributing the load, are still employed.

The abutting of upper ends of posts against top chords and relying on this connection to transmit the stress is a feature in bridge design that cannot be too severely condemned. Unfortunately, it is very common in the highway bridges of the West.

Another glaring defect is bad shop-work, especially where the correct rules for riveting have been violated and the metal injured in consequence.

Both upper and lower ends of batter braces are still made fixed, although modern practice demands that they be hinged.

Trestle bents are seldom properly sway braced, and means for their expansion and contraction with changes in temperature are rarely provided.

This by no means completes the list of errors in bridge design, but enough has been said to show conclusively that it is necessary to study correct principles before attempting to proportion structures upon the strength of which depend the lives of the community.

During the last year, or since the first edition of this pamphlet was issued, there has come into prominence a new style of structure for highways, viz., the cable suspension bridge. In its original form it consisted of strands of twisted telegraph wire, forming cables less than one inch in diameter and spaced two feet apart, to support two-inch transverse planks, clamped occasionally thereto. These cables passed over two wooden bents, resting on mud-sills or piles, and around anchor piles or "dead-men" in each bank.

The prominent feature of these bridges and the one which commends them most highly to county commissioners, is their cheapness. They cost three or four dollars per lineal foot, and are sold for six. Moreover, the price per foot does not increase with the length of span, because the same number and size of cables are employed whether the clear span be fifty feet or one hundred and fifty. In fact, the actual cost per foot is really less for a long span than for a short one.

Another great advantage which this class of bridge possesses is that it can be very quickly erected at any time and anywhere, for telegraph wire is a merchantable commodity that can be purchased at almost any hardware store in the country, and, barring the iron nails, this is the only metal required.

A certain company had at first the exclusive privilege of furnishing the country with this great boon, but very shortly another company stepped in to divide the honor and the profit. This new company effected some improvements (?) on the original design, the most notable of which are as follows:

First, they substituted gas-pipe bents for the wooden ones, and gas-pipe piles braced by stone walls for the anchor piles or "dead-men." Then they divided the clear span into three panels, putting an upward cambre in the cables by means of a heavier cable on each side of the bridge, using gas pipe for the floor beams. The beautiful feature of this arrangement is that by twisting on the outer cables with iron bars, enough initial stress can be brought upon the other cables and the floor beams to produce rupture without any live load whatsoever upon the structure.

The great superiority of these cable bridges over the ordinary truss bridge is partially offset by one unimportant feature, viz., that the former are absolutely unsafe. This is not, perhaps, so serious a matter as one might at first imagine, because the traveler in passing over a highway truss bridge is uncertain as to whether he is risking his life, while in passing over one of the new cable bridges he is positive of it.

The author was called upon, a few months ago, to inspect and report upon one of these improved-style cable bridges which was just completed in Southern Kansas. The following extracts from his report may prove useful to county commissioners in the West, because the remarks concerning this particular structure will in general apply to all bridges of this type.

"On account of the upward cambre in the roadway cables between the gas-pipe piers, the horizontal 4 inch gas-pipes, termed by the contractor 'needle-beams,' must act as do ordinary floor beams, for which purpose they are absurdly weak. The live load ordinarily specified for county bridges would demand floor beams twelve times as strong as these 'needle-beams.' It is practicable to remove these and replace them by heavy timbers, and I would recommend your so doing, were this the only serious fault in the bridge, which, I assure you, is by no means the case.

"The ordinary live load previously mentioned would strain the wire in the main cables to 49,000 pounds per square inch, provided the wires were parallel and equally strained. But as they are twisted in a manner that is very irregular when compared with machine-twisted cables, it is not improbable that some of the strands are strained as high as 60,000 pounds, or even 65,000 pounds per square inch, especially in the neighborhood of the beam hangers, where the cable is split to allow the hangers to pass through.* . . .

"My calculations show that the floor cables have been strained from 25,000 to 30,000 pounds per square inch merely by the adjustment of the main cables. . . .

"The two-inch floor planks would be overstrained by a wheel load of 2,000 pounds under the assumption of perfect adjustment and equal deflection of floor cables; but as several causes tend to prevent anything approaching such equality, it is evident that the planks must be seriously overstrained by passing loads. I observed their action when a lightly loaded wagon was going over the bridge, and found the deflection and vibration to be excessive. What will it be, therefore, under the passage of a full load after the cables have had time to get still more out of adjustment!

"The tendency to overturn the anchorages cannot be calculated, owing to the fact that the working stresses on the cables are indeterminate; but this much it is easy to determine, viz., that the proportions of the anchorage are such that good practice would not permit of the cables being strained more than 13,000 pounds per square inch, which amount is certainly exceeded, even when the live load is confined to the middle span. . . . In short, there is no portion of this structure, unless it be the gas-pipe piers, that will provide sufficient strength for ordinary loads. . . . The best thing to do with the affair is to take it down and replace by a properly designed iron or combination bridge.

"The building of these wire cable bridges ought to be prevented by law, for they are death-traps of the worst description. From all I hear I judge that the structure which I have examined for you is by no means the worst of its class to be found in Kansas.

"Whether you pay for this bridge or not is no affair of mine; but for your own sake I most seriously advise you to take it down, and to warn the other county commissioners in your State against building any more structures of this pattern."

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*This wire was afterward tested. It failed to develop an ultimate strength of 80,000 pounds per square inch.

CHAPTER V.

HOW BRIDGES OUGHT TO BE BUILT.

The determination of the style of structure for any stream-crossing is to a great extent a matter of judgment, and, therefore, dependent upon practical experience. The principal factors are the capacity required, the hydraulics of the stream, and the amount of the appropriation.

The capacity will have to be determined by estimating the amount and character of future traffic. The hydraulics of the stream will, in connection with a special study of the "economics" of the crossing, determine the number and length of spans, while the amount of the appropriation will settle what kinds of materials to use for both superstructure and substructure.

If the appropriation be small and the estimated future capacity large, it will be necessary to put in a temporary superstructure on either a permanent or temporary substructure, preferably the former, with the intention of replacing the bridge when worn out or inadequate for the travel.

The determination of the number and length of spans is a subject altogether too intricate to be treated here. It will suffice to state that spans are, for false motives of economy, generally made too short, and that if there be no limit to the number of piers, the greatest economy will generally exist when the cost of the substructure is equal, not to that of the superstructure, as is usually stated, but to that of the iron in the trusses and lateral systems.

For clear spans of twenty, or even twenty-four feet, the cheapest method of crossing is by wooden joists. For spans between this limit and forty feet it is better to use deck-plate girders with transverse wooden joists. For spans between forty and sixty-five feet, triangular riveted deck girders with transverse wooden joists will be found the best. For spans from sixty-five to ninety feet pony trusses with floor-beams riveted to posts and top chords braced to cantilever brackets will be most satisfactory; and for greater spans through Pratt truss bridges. When the span exceeds two hundred feet, there is economy in halving the panels and inclining the top chords near the ends. The double intersection or Whipple truss, although allowable, is not as good as the one last described; moreover, it is doubtful whether its use would involve any economy of material.

The best length of panel to use is about twenty feet, but this may be increased to twenty-five feet or even more, when iron joists are employed.

The most economic depth is generally from one-fifth to one-seventh of the length of the truss, depending upon the length of the span and the style of the truss adopted. In general, wooden joists should vary in section from 3 x 12 inches to 4 x 16 inches, and should be spaced between eighteen and twenty-four inches from center to center. Either yellow or white pine, although not so strong, is preferable to oak, which warps and splits and is considerably heavier for the same strength.

Floor-beams should be made as deep as economy of material and a proper consideration of flange-width will permit, and should be riveted to the posts whenever such an arrangement be practicable, as it nearly always is. The unsupported length of a floor-beam should not exceed thirty times the width of the top flange. It is generally better not to diminish the depth of the beam web near the ends, owing to the reduction in space for the rivets which connect to the posts, and to the lessened resistance to shear on the web.

When the wooden joists pass over the floor-beams great stiffness is obtained, at a very trifling cost, by placing a wooden shim between them, bolting it to the top flange of the beam and spiking the joists to it. When the limited distance between the surface of the floor and the lowest part of the superstructure will not permit the joists to pass over the floor-beams, they should rest on angle-iron brackets riveted to the floor-beam web, the upper surface of the joists being flush with the top of the beam, or higher when a shim is placed over the beam for the purpose of receiving the floor-spikes. The angle brackets should be connected to the web by at least three seven-eighth-inch rivets, and there should be a hole in each for a spike or screw to pass through into the joist.

Lower lateral rods of small section may be attached to the webs of floor-beams as near the ends of the latter as practicable. In long spans where the wind stresses are great, it is well to let the middle of the beam be at the level of the center line of the bottom chord, cut a space in the web to receive the chord heads, and use double lateral rods, one set being attached to beam or post near the upper flange, and the other near the lower flange, thus balancing the stresses.

In general it is well to observe the following rule when practicable: "All the members which converge to an apex should have their axes meet in a point." Otherwise the induced stresses due to the eccentricity in the connection must be provided for. The larger the structure the more important it is that this rule be followed.

In the upper lateral systems of through bridges the stresses are ordinarily so light that the rods can be attached to the upper surface of the chord by means of three short pieces of angle-iron, through one of which the upset end passes, all three being riveted to the chord-plate.

Upper lateral struts, except in very wide bridges, should be made of four angle-irons with a single system of lacing bars and end stay plates between, the ends of the struts being riveted to the chords in a most efficient manner.

Portal struts should be rigidly riveted to the batter braces. They should be proportioned to resist both direct and transverse stresses to which they may be subjected by the wind pressure. The correct method of finding stresses in sway bracing is given in Burr's "Stresses in Bridge and Roof Trusses," and in the author's treatise on highway bridges. The proper section for portal struts for small bridges is the same as that for upper lateral struts, but for large structures it is necessary to use either two channels with two systems of lacing, or four angles with four systems of lacing.

Portal rods may be connected in various ways which will be efficient.

The effect of wind pressure upon all connections should be carefully calculated and provided for. This important matter is overlooked in nearly all ordinary highway bridges.

Both posts and batter braces should be made with hinged ends; the former for convenience in erection, and the latter to insure an evenly distributed vertical pressure on the pedestal. The post channel webs may be turned either parallel to the plane of the truss or perpendicular thereto, according to which arrangement is the more convenient and economical. Generally, the former is the preferable method.

Sections of all members, both tension and compression, should invariably be balanced in respect to the line of action of the stress.

Hip verticals should be made similar to the posts in section so as to add to the rigidity of the structure and afford a substantial attachment for the floor-beams.

In narrow bridges—say those under eighteen feet clear roadway—the bottom chords in the end panels should be made capable of resisting compression, otherwise they will tend to buckle under wind pressure.

Stay plates at the ends of a system of lacing should be made square, and the rivets in them should be spaced nearly as closely as allowable. Their thickness should never be less than one-fiftieth of the distance between opposite rows of rivets. This rule is nearly always neglected in designing highway bridges. The sections of the lacing bars should be of the sizes specified.

When cylinder piers are used, the floor-beams at the ends of spans should rest on the pedestals, and under no circumstances should they be riveted to the shells of the cylinders. The reason is that these shells may in time rust out, for there is no way of painting their interior.

Sizes of pins should receive careful attention, and the bars upon them should be packed scientifically so as to reduce the bending to legitimate limits. Every pin bearing should be proportioned to resist properly the greatest stress in the member, and there should always be enough rivets to develop the full capacity of the reinforcing plates.

The standard rules for riveting should be closely followed, large rivets being used when practicable.

Under no circumstances whatsoever should any rivet be used in direct tension; it is always possible to design details that will avoid the use of this most objectionable but too common practice.

The limiting sizes of sections given in Chapter VII. should invariably be adhered to, as the use of smaller sections would tend to produce injurious vibrations.

The best style of trestle is that which consists of alternate short and long deck spans, say twenty and forty or fifty feet, the girders being of the plate girder or triangular riveted type (one system of triangulation only). The economic lengths of span will of course depend upon the height of the columns. The latter under the short spans should be braced so as to form towers, provision being made for expansion and contraction both longitudinally and transversely. The long spans should also be arranged for expansion at one end. The angle-iron diagonals of the girders should be attached to the flanges at each end of both legs by means of auxiliary pieces of angle-iron, and great care should be used in determining the number and size of rivets required for each connection.

When alternately short and long spans cannot be employed, provision must be made to compensate for the absence of the braced towers, by using either rocker bents or some equally efficient arrangement.

Pin-connected trusses for trestles are inferior to the triangular riveted girders, owing to their lightness and want of rigidity. When properly proportioned they are also more expensive. Deck girders for trestles are more economical than through ones, and are much better also, if the structure have sidewalks.

CHAPTER VI.

A PROPOSED ASSOCIATION OF HIGHWAY BRIDGE BUILDERS.

In Chapter III. it was stated that the pooling system is a necessary evil, and that bridge companies must sooner or later, in some way or other, be paid by the public for all the expenses incurred in preparing for and attending lettings. As matters stand, this tax is very unequally divided, because when work is let "on a fight," the buyers get their bridges for about cost or even less; consequently in case of a pool being formed, the buyers will often have to pay for all the expenses of all the bidders, not only at their own letting, but also at several other lettings where the co tractors were unsuccessful in forming a pool. Such a division is m decidedly unfair, therefore the author will endeavor to show in t chapter how the tax for legitimate expenses may be equitably divic among all the buyers, and how the amount of this tax may be reduced proper limits by forcing out of the business all irresponsible contractors

As stated in Chapter I., the author some five or six years ago deavored to accomplish this purpose, not only by publishing a descripti of the method to be employed, but also by forming an association of We ern highway bridge builders.

As the paper referred to is pretty complete, it will be reproduced h in full and afterwards supplemented. It reads as follows:

"That such an organization as the one above mentioned is rea needed is apparent to every reasonable man who travels to any extent the Western country.

"Not more than ten or fifteen per cent. of the highway bridges the West are built upon sound specifications, and of these many are as strong as they are claimed to be. This is proved by the number bridge failures of which one reads from time to time in the newspape though, if the truth were told, such matters are very often hushed up, the failure is attributed to a washout, a tornado, or some other cause wh man is supposed to be powerless to resist. It is true that once in a wh there does come a hurricane powerful enough to overturn the best bridges, but such storms are few and far between.

"Every bridge should be built so as to resist, without injury to any its parts, the highest wind pressure observed in heavy gales. As washouts, they are usually due to the short-sighted policy of the sup visors, to whom is entrusted the responsibility of directing how the brid shall be built. Rather than make the spans a little longer and raise ther little higher, thus increasing their cost and that of the piers and approach they prefer to restrict the stream with the foundations and to run the r of high water reaching the bridge. There is really no excuse for washout except a gorge of ice or timber, and even this can, in most cas be avoided. But washouts and tornadoes are not the true causes of m of the bridge failures, for many structures succumb without the ass ance of either high wind or high water; they fail simply by reason faulty design, which makes them unable to withstand the stresses dev oped in them by passing loads. Worse than this—many of them scarcely fit to sustain their own weight!

"This is a pretty bad state of affairs, and what has been done ameliorate it? Very little.

"About a year ago Prof. Vose issued a pamphlet entitled, 'Bric Disasters in America: The Cause and Remedy,' which should have do considerable toward raising the standard of American bridges. Unfor nately the work has not met with the reception it deserves, and brid are built in about the same style as they were before its appearance.

"The 'remedy' suggested by Prof. Vose is the appointment of St engineers, whose duty it would be to examine, before erection, the d grams of stresses and sections of all bridges to be built in their States, and inspect at least twice a year all the existing bridges.

"The pamphlet concludes as follows:

> "'Thirty bridges on an average break down in the United States every year. No system of inspection or control at present existing has been able to detect in advance the defects in these structures or to prevent the disasters. A system, practical, simple, and inexpensive, can be had, which, if properly carried out, will insure in nearly all cases, if not all, the public safety. It lies with the public to say whether or not it will have such a system.'

"Well, the public, by the indifference it has shown, has clearly indicated that it does not deem such a system necessary; and nothing but a long series of bridge disasters involving great loss of human life will ever awaken it to the fact that something must be done to prevent such accidents.

"Now, why can not the bridge companies themselves undertake the duty that the public refuses to assume?

"Every first-class bridge company recognizes the fact that it is to its interest to build good, substantial structures, but many of them are forced by the closeness of competition with inferior companies and local bidders to erect bridges that are not approved of by their engineers. They would, probably, very gladly do what they could to improve the bridge business, but are restrained by force of circumstances.

"To show how the difficulty may be overcome is the object of this paper.

"Let there be formed during the coming winter, when bridge builders and engineers will be comparatively at leisure, an association of all the principal bridge companies of the West, the object of which shall be to *enforce* the building of firm, substantial structures.

"The word 'enforce' is used advisedly, for such an organization would, on account of the standing of its members and the praiseworthy object of its existence, wield great power. It could dictate to county commissioners what quality of bridges they should build, and could prevent the erection of all bridges not up to a certain standard. By taking into the association the manufacturers of bridge material, an arrangement could be made by which local bidders would be unable to obtain iron for doing inferior work. This would soon render the existence of that genus a thing of the past.

"By the term local bidder is meant an individual residing in the county where the bridge under consideration is to be built, who has assisted in some capacity or other at the raising of two or three structures or has been practicing the trade of carpenter or blacksmith, and who, with no knowledge whatsoever of mathematics or the laws of mechanics, gets into his head the insane idea that he can design and build bridges and proceeds to put that idea into practice. Nearly every county contains one specimen of this kind. It is to these men as well as to inferior companies that are due the low standard of American highway bridges, and the numerous disasters which occur every year.

"The organization of the association proposed would be a simple matter: the first step to be taken at the meeting of the representatives after choosing a chairman, would be the appointing of a committee to draw up a constitution and by-laws, and another, composed of the best engineers, to prepare specifications and tables regulating the style a strength of bridges to be built in future. Sufficient time should allowed these committees in which to report, as there would undoubte be a good deal of discussion before all the various theoretical and techn points could be satisfactorily settled.

"The general scheme of the association should be that each comp deposit with the treasurer a certain sum of money, say one thous dollars, to be held by him as long as the company is represented in association as a guarantee that it will comply with all the rules and re lations of the association. Should at any time the company, or any of authorized agents, fail to do so, a standing committee of three to act judges should decide as to how much of the deposit shall be forfei for the offense, and the company should be deprived of all the rights privileges of membership until such time as the amount forfeited be placed. In order to insure its speedy replacement, a further fine of much per month, after the first month, should be added until the deposi brought up to its original amount.

"With the money accumulated from fines, interest on guarantee posits and, if necessary, annual dues, the association could make ma needed experiments upon resistance of bridge materials, and could h the results printed in a publication of its own. Discussions in the pap of the association from time to time would originate new rules, and t elevate the standard for bridges. But—some one may say—suppose t or three companies refuse to enter the association, will not this be su cient to prevent its organization? Not at all. Should any company ref to join the association and continue to build inferior bridges, it would s be forced either into the association or out of the business.

"This statement may sound a little like an infringement of the pr ilege that every American has to do as he pleases and may seem like co cion of the weak by the strong, of the few by the many; but such need be the case. The privilege of membership would not be withheld fr anyone willing to deposit the guarantee and to comply with the regulati of the association.

"Some one may suggest that, if all the bridges in the country built upon one set of specifications, there would be no chance for impro ment by variation in design. By no means; the specifications of the as ciation would limit the *weakness* of bridges, not their *strength*, and a one would be at liberty to make all the improvements he might des and ought to be encouraged to do so by the association as a body.

"Some one may observe that, if all bridges are to be built upon sci tific principles, it would be a little hard upon those who have not recei a scientific education. All very true, yet such persons have three course choose from: first, to post themselves; second, to employ skilled lab third, to build after the model of some one who is better instruct Besides, the tables, etc., of the association would be of great assistanc such persons, enabling them to make good designs with very little cal lation.

"But then—some one may object—this association would be a m opoly. In one sense perhaps it would, in that it would prevent ignor men from doing work which ought to be left to those who have sp years in educating themselves for the purpose.

"In short, there can be no reasonable objection to the proposed association, and not only would it be a benefit to the bridge companies, but would be also a great boon to the country at large."

The additions to the preceding which the author would now make are as follows: In the first place, let it be understood that the main object of the association is the insuring to its members a fair profit on every contract which is taken, and that the secondary object is the improvement of bridge designing. On no other basis can bridgemen be induced to form such an association.

Let a certain tax be levied on each bridge built by any member of the association, the amount of the tax being a function of the length of span, total live and dead load per lineal foot and intensity of working tensile stress for bottom chords. Moreover let the association announce in the newspapers and by circular to county commissioners not only its existence, but the reasons therefor, the tax to be levied, its rules and regulations, etc., in short, let everything connected with the organization be fair and above board.

Let the specifications of this treatise, or others very similar to them in both character and scope, be adopted by the association and adhered to most strictly.

Let the association guarantee to buyers that any structure sold by any of its members shall be in every particular up to these specifications, and that, if not so, the structure shall be replaced at the expense of the association. In case of such replacement of any structure, the contractor responsible for same should not only be made to refund to the association its entire expenditure, but should be fined besides.

For repeated infraction of rules, or non-payment of fines, any member of the association should be suspended or expelled.

The association should be managed on a purely business basis, a competent engineer and business man being made manager, paid a high salary, and furnished with all the necessary clerical assistance. A good deal of power should be granted him, but any member differing with him in respect to a decision should have the option of an appeal to a standing committee composed of three of the leading engineers and business men of the association. The decision of this committee should be final.

The main requisite for the success of such an organization is good faith backed by a heavy forfeit.

The laws of the association should be well considered, just, and very stringent.

The revenue from the tax should be used to pay all expenses, and the remainder should be divided annually among the members in direct proportion to the total value of the contracts which each has taken during the year.

The results of the formation of such an organization would be that very soon no bridge supervisors would dare to let a contract to anyone not a member of the association, that the total cost of bridges would be reduced, that the profits to responsible contractors would be increased, and last, but not least, that every highway bridge erected would be a creditable piece of engineering work instead of a vile death-trap, as is too often the case under the existing order of affairs.

CHAPTER VIII.*

REMARKS CONCERNING THE APPLICATION OF THE SPECIFICATIONS.

The object of this chapter is to explain to those who have not made a special study of bridge designing, the reason for some of the requirements given in the preceding chapter, and to expand a little some of the directions that were of necessity in the specifications made rather concise. The various points to be treated will be taken up, as nearly as may be, in the order in which they occur in the specifications.

The reason why the live load for trusses of long spans is less than that for the floor system of the same structure is because it is possible to load a panel length to the maximum several times a day, while the whole span would probably never be subjected to that load.

The cost of a bridge is increased considerably by specifying that the floor and primary truss members must be proportioned to carry a road roller. So unless it is probable that a road roller will cross the bridge several times a year, it would be advisable not to figure thereon; but to insist that the roller be disconnected and transferred a piece at a time in a wagon.

The wind pressure adopted in the specifications is a trifle lower than that usually called for. The reason is that the author prefers to specify a fair wind pressure and proportion the whole structure throughout for the effects of same, rather than to insist upon a higher one and neglect the effects of all the induced stresses that it may cause.

The reason why joists are proportioned by the deflection formula for uniformly distributed loads, and by the extreme fibre stress formula for concentrated loads, is that the uniformly distributed loads may pass rapidly and tend to set up vibration, unless the joists have the requisite stiffness, while the heavy concentrated loads will be applied very slowly, necessitating ample strength, but not great stiffness.

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* Chapter VII has been omitted, for the reasons given on pages 205 and 208.

Wearing floors will be necessary only on bridges where the traffic is great. In other cases they would involve a useless expenditure of money.

Shims under guard rails are to facilitate the escape of water and thus lengthen the life of the floor and guards.

Angle iron facings on guard rails are used where the structure is upon a heavy grade, because teamsters with heavily laden wagons are apt to brake their vehicles going down grade by keeping the wheels against the guard timber. Under these circumstances without some protection the guards would soon wear out.

The peculiar section for the wooden hand-railing, *i. e.,* one 2 x 6 inches on flat and another timber of the same section directly under it on edge, is employed to provide for a row of men seated on the railing; a condition by no means unusual.

The reason why there is an inferior limit to the use of the double-intersection or Whipple truss is to avoid very small sections, consequently this limit should vary with the carrying capacity of the bridge and with the " factor " for the trusses.

Pony truss spans are limited in length on account of the unknown carrying capacity of the top chord, which is only at best partially stayed against lateral motion.

The principal objection to the use of continuous spans is that if one of the piers should settle a little—no uncommon occurrence—the assumed conditions affecting stress distribution would no longer hold, and certain parts of the trusses would be badly overstrained. Moreover, continuous spans involve reversing stresses, a condition of affairs to be avoided whenever practicable.

It is only in unusually deep and narrow bridges, or in bridges for localities where the wind pressure is liable to be excessive, that it will be necessary to figure upon the bending effect of wind pressure on posts and batter braces, or the direct wind stresses in chords.

Stiffened end panels will, in general, be required for bridges having less than eighteen feet clear roadway; but if the assumed wind pressure be higher than usual, this limiting width will be increased.

Alternating stresses occur in the case of bridges with wide projecting sidewalks, especially if the main roadway be narrow; in some of the primary inclined struts of trusses with halved panels; and in brackets under single portal struts and upper lateral struts without vertical sway bracing. They occur also in the truss members of swing bridges, and, as before stated, in those of continuous spans.

End stiffeners of plate girders *resting on supports* will have to carry the total shear, because the web does not touch the supports, hence they must be proportioned to resist the total reaction; but when the end stiffeners act as connecting pieces to other members, there is no correct way of determining their sections, except to provide ample bearing the rivets and to make the metal not less than one-quarter of an inch thi An approximate method of finding the sectional area of these stiffen is to divide the end shear by an intensity fifty per cent. greater than t used for the case of girders resting on supports.

The Manufacturers' Standard Specifications for Material, etc., ha been adopted not because they are the most rigid used, but because metal therein specified is the best that can be had for the money, and at same time good enough for all practical purposes—in fact far superior that commonly used in highway bridges.

CHAPTER IX.

DISCUSSION BY ENGINEERS.

In this chapter there is given a large portion of the discussion prominent engineers and bridge builders, referred to in the Prefa together with a portion of the author's reply thereto.

It was published in full in the "Journal of the Association of Engine ing Societies" for November, 1888.

Those portions of the discussion relating to purely technical matt have been omitted, for the reason that they are of interest only to brid engineers, nevertheless the said portions have been useful to the auth in the preparation of this second edition.

DISCUSSION.

By Samuel G. Artingstall.

I think there can be no difference of opinion as to the necessity for i provement both in the way of awarding contracts for these works and in t design and construction, so as to secure at least a safe structure for the u of the public. The difficulty seems to me to be how this can best be acco plished. A combination of bridge builders does not appear to me as pr ticable, for the reason that there are too many who would try to take a vantage of this combination by underbidding and building a structure whi would not strictly be in accordance with the specifications, and I do n clearly see how this can be avoided unless the trustees employ a compete expert to advise, not only on the merits of the different designs submitt in competition, but also to see that the structure is built with members

suitable scantling, and that the workmanship is good throughout. In my opinion the way to get substantial highway bridges is for the legislatures of the several states to insist upon minimum strength in the several classes of bridges, and to appoint an expert engineer with such assistants as may be necessary, to whom all designs for highway bridges must be submitted and receive his approval before being built, and after erection to be examined and accepted before being allowed to be used for public use. If some such law could be faithfully executed in any state, contractors will soon improve the character of their designs, and while competition would not be restricted, bridges would be safe and the public would soon gain confidence in their security.

By G. Bouscaren.

This movement against unscrupulous highway bridge builders is highly commended. but should be extended, I think, to the same class of dealers in railroad bridges.

I have very recently completed the inspection of some 600 miles of railroad, equipped with a variety of wooden and iron bridges, and with the fresh evidences of sinful designing collected thereby, I am more than ever impressed with the necessity of protective regulations broad enough to cover all classes of bridges. In fact, if any distinction were to be made in that respect as between highway and railroad bridges, it is quite clear to my mind that the latter's interest is by far the more important of the two.

First—Because the public has some means of redress against careless or fraudulent awards of defective highway bridges, but it has none against railroad managers or construction companies.

Second—Because a highway bridge can be seen and criticised by any one passing over it, and attention may thus be called to glaring defects in its construction, while the true character of a railroad bridge must remain hidden to all but the inspector, if there be one.

Third—Because the number of people who risk their lives and limbs daily on dangerous railroad bridges is tenfold that who do the same on highway bridges.

The necessity for placing all classes of public work under the supervision of a competent expert who is not himself a contractor is universally admitted. Unfortunately there is no law making such employment mandatory, and if there was, it is likely that the same parties who award their work to the lowest bidder regardless of quality and quantity would also select the cheapest "expert" regardless of quality.

A law regulating the construction of bridges should therefore provide general specifications for the same, and a competent expert should be appointed by the Governor of the State to inspect and verify the work done under these specifications.

The uniformity of specifications for all the states, although desirable, is not a matter of prime importance. I think that all engineers engaged in the independent practice of their profession agree now practically as to the main points, and the differences to be found in their specifications are but different modes of arriving at the same results.

But I consider it essential that the specifications, no matter by whom prepared, should be the work of an engineer entirely free of attachment with any manufacturing or contracting firm, otherwise the very object which they have in view would be defeated.

You will pardon me for saying that the manufacturers' and contractors' specifications, which you have made an adjunct to your own specifications, is the best example I can give of what I mean to convey.

As long as the object of the profession will be to do the most with the least money, and at the same time to place safety before cheapness, the engineer must aim to raise the quality of materials as well as the perfection of workmanship, because in doing this he eliminates many of the unknown elements which necessitate the so-called "factor of safety." Now, the manufacturers' and contractors' specifications do precisely the reverse of this.

By lowering the grades of materials and discouraging the thorough testing of the same, they introduce new elements of uncertainty, and make it necessary to increase the factor of safety, thus increasing the weight of material used and rendering their plea for economy an illusory one, if the same measure of safety is to be retained.

These specifications were condemned by all independent engineers present at the convention where they were discussed, and the only reason which I can ascribe for the persistent effort made in favor of their adoption is to allow manufacturers who cannot produce the best grades of iron and steel to compete with those who can.

I hope that I may win you to my side in this question; but if I fail to do so, you will understand my reasons for not endorsing your circular.

I am ready and would be glad to join in any action tending to the effective protection of the public in the matter of bridges. So many of our most able men are personally interested in the question as contractors or manufacturers that unity of action in that direction cannot be accomplished without some sacrifice on their part, which, unfortunately, they do not appear, as yet, ready to make.

To the above, which was written as a letter to Mr. Waddell, I add nothing, excepting to emphasize my objections to the "contractors' specifications," which are made a part of Mr. Waddell's. I should very much regret to see them endorsed generally, for the reason given in my letter, and do not think that any unity of action tending to their support could be secured. I think it would be an easy matter for engineers to arrive at an understanding as to general specifications for highway and railroad bridges, which could serve as a standard for the regulation of that class of construction; but specifications, however carefully drawn, are of little value without proper supervision to interpret and enforce them. Hence the necessity of legislative action to give them force of law.

By W. H. Breithaupt.

Mr. Waddell's paper is most timely. Such a reform is particularly needed in the building of highway bridges in the West. Our immediate field of action is to agitate for an improvement in this State. By the laws of Missouri, county bridges are now let by public outcry to the lowest bidder. That

this is not a good method of obtaining efficient work and of obtaining it at its true value has been sufficiently proved. Letting by tender is much the better way. Awarding of contract should be dependent on some one not in any way interested in any of the tenders; and to this there should be state officers as outlined in the pamphlet under discussion. The remedy there given appears to me to be much more feasible and leading to more reliable results than could be obtained by the proposed association of highway bridge builders. Right of inspection certainly belongs to the purchaser; and if he wants advice as to the article to be bought, he will go to some one independent of the seller. So in the case of the buying of bridges the purchaser would want to rely on the judgment of an outside engineer.

A scheme for state supervision might be generally outlined as follows: First, there should be a state engineer of bridges, or state bridge inspector. His holding of office, whether by appointment or election, and the former would seem much the better, should be dependent on his having had a certain number of years' experience in bridge work, and at least two years' experience in designing and in actual charge of work; and of his having successfully passed an examination, technical and practical, by competent engineering authority, state or national, the former for some reasons preferable.

The engineer should have the appointment of assistants, after they had passed a prescribed examination and otherwise proved their fitness. All bridges of any importance, say of span beyond a certain length, in public use, both highway and railroad, should then be subject to being passed on by the state engineer of bridges, either on his personal investigation or investigation by one of his assistant engineers. The qualification as assistant state bridge inspector might be given to any engineer proving his fitness. * * * * * *

By W. H. Burr.

Probably no one will dispute the statement of Mr. Waddell which he has so forcibly supported, to the effect that much of the highway bridge business of the country is productive of most dangerous structures, which would not be tolerated under intelligent and honest supervision on the part of the proper county, town or city authorities; but personal examination of a large amount of highway work during the past two or three years leads me to believe that at least some highway bridge builders are doing fairly good work, and are entitled to the confidence of the public. Such builders would doubtless be glad of any movement that has for its objects the improvement of highway bridges and the extraction of good work from the unscrupulous builders or else their extinction.

So far as the flimsy and dangerous bridges are concerned, I believe it may be confidently stated that two causes render their existence possible: one is the combined ignorance and unscrupulousness of their builders, and the other, the ignorance and possible or probable corruption of a large number of the highway commissioners in many places, both evils being aggravated by the culpable apathy of the general public. The failures occurring every month demonstrate the existence of hundreds of miserable structures, and the widest possible publicity given them is the most potent factor in dissipating the indifference of the public. Interested engineers, as well as other interested and public spirited men, should have some concerted system by which every bridge failure would receive such attention that all essential details regarding previous condition and causes would be collected and permanently preserved, together with the name of the builder and date of erection or time of duration of the structure. The amount of loss of both money and life entailed by the wreck should also be ascertained. A careful and accurate account of the failure based upon the data thus obtained should then be written and given the widest publicity both in all the engineering papers of the country and the principal dailies. By such means the general public would be brought to realize not only the great losses caused by such inferior structures, but also the imminent danger in which a large portion of the community daily traverses the highway bridges of the country. The wide publication of the names of the builders of these tumble-down bridges would be an excellent advertisement of the dangerous character of their miserable wares, and would serve to notify the public that they and their business agents should be avoided. The constantly recurring notices of these disasters and their destructive consequences would stimulate in the public mind a growth of the right kind of interest in the matter of highway bridges, and would soon effectually dissipate the existing apathy and indifference. Such a constantly educating influence would soon induce or force the appointment of capable highway bridge commissioners with at least some integrity, who would not allow those builders to bid whose names become prominent through failures.

In this or some similar manner only, I believe, can public apathy be removed and a correct public sentiment be created. Unsupported by public sentiment, license, legal enactment or commissioners appointed by the American Society of Civil Engineers or any other body will be certain to result in vain efforts, whose failures will leave the evils more firmly fixed than before. With it, however, the County Commissioners will need no extraneous impulse to seek tenders from either honest or honorable and competent builders, or the services of a consulting engineer who will furnish them such advice as will lead to the purchase of a substantial bridge.

The benefits of a pool are, to my mind, not by any means clear, although I do not doubt that which Mr. Waddell proposes, if conducted in the manner he indicates, would serve to remedy many existing evils. Whether the organization could be kept in the original channels seems to me, in the light of human experience, somewhat doubtful.

One thing is clear, however, in fact two things are clear, the present system of unlimited and indiscriminate invitations to tender for highway work breeds most pernicious evils and is most extravagant and expensive to counties, cities and towns. Such a comprehensive method induces bids from the good, bad and indifferent, with the first in a very small minority. Good designs are thus put alongside of the most wretched clap trap, which appears under a correspondingly low figure and is usually accepted. This is the first step toward a subsequent failure near at hand. Again, traveling and other expenses and "boodle" must, of course, be paid by the public who buy the bridges, and the greater the number of bidders, correspondingly greater must be the amount of expenses and "boodle." If the wise and discreet officers of town, city or county were to put their heads together to deliberately discover a method by which their constituents should pay the greatest possible price for the poorest and most dangerous bridge that would stand up in a presentable manner long enough for the builders to get their pay, they could scarcely succeed better than to advertise their bridge lettings in the local papers in the usual manner.

Invitations should be extended to a few responsible builders only, whose reputations and known competence and honesty would be a guarantee for satisfactory designs and substantial work as well as proper methods, whether bids are mailed or submitted in person. Highway commissioners utterly unfamiliar with the first principles of engineering and an easy prey to the devices of sharp and unscrupulous bidders can ill afford to have any conference with them, and should not venture to do so; but an open advertisement brings in a swarm of such parties and generally repels the best builders, since they know that honest structures cannot be furnished at the prices of their unscrupulous competitors. Whenever highway commissioners follow the example of the railroads, and invite a small number of bids from reputable parties, they will get good work and safe structures at economical prices, and not till then. Such conditions only will reduce expenses, and eliminate "boodle."

Little need be said regarding the specifications submitted by Mr. Waddell. They are admirable, and no exception can be taken to them. The most competent engineers may differ in opinion over points of detail, but such differences are quite unimportant and of no consequence.

By C. E. H. Campbell.

Professor Waddell very truly states that the average iron highway bridge as built in the West to-day is in many respects inferior to that built five years ago. As to the causes of this state of affairs, they are many and complicated. Eight years ago the average number of bidders found at a bridge letting was six, and every one of them was capable of designing and constructing a fairly decent structure; to-day the average number of bidders is fourteen, consisting of the following variety of talent: Seven representatives of companies owning shops, and competent to turn out good work; two contractors of reliability who do not operate shops; five incompetent hangers-on who follow the legitimate contractors from place to place for the purpose of getting money enough from them in the way of pools to live on without working for it, and who generally have more to say and more advice to give the officials who have the business in charge than the legitimate bidders have. This is the genius who is known by the honorable and appropriate title of Scalper.

This term should apply to any man who, after receiving a contract to construct a bridge upon a certain plan and specification, wilfully and purposely cuts down the sizes of materials in such a manner as to render the structure unsafe; and as has often been done, mutilates it to such an extent that some parts are only half as strong as others. This mutilation generally occurs in the rolled channel bars, lateral systems, floor beams and small details. The sizes of bar iron are seldom if ever changed, because even a

County Commissioner can measure them and discover the shortage. Th diagrams of stresses which are submitted by the majority of bidders and th sizes of materials specified are generally correct, but a comparison of thi diagram with the structure as built is what will tell the tale. This is rarely if ever, made.

It may be asked how are communities going to avoid the existing stat of affairs. It seems to me that one of the easiest methods would be to refus to entertain a bid from any person who is not prepared to demonstrate hi ability (theoretically, practically and financially) to build the bridge desired Then to control the proclivities of those who may be called competent builder would not be such a difficult matter. A community could either employ a expert engineer to make designs for their work to suit their requirement and means, then invite bids on said designs, and retain their engineer to se that the contract was carried out in every particular, or, if they accept th tender and designs of any bidder, require him to furnish copies of his work ing drawings to submit to the inspection of an expert, or if they canno afford to do all this, let them accept what appears to them the best plan an specification and bid, from one of the bidders, then place the county seal o all papers, and not permit them to pass out of their hands or to be changed and when the bridge is complete to take these specifications and go ove every part of the structure and measure the sizes, and if they find any varia tion from the specifications that upon investigation diminishes the capacit of the structure from that represented by the contractor, refuse to accept o pay for the bridge until the scant parts are made good. There is no honest o responsible contractor who will be afraid to accept these conditions, and an man who would not agree to the same should not be awarded a contract. Th contractor should also be held accountable for any and all defects of construc tion that might be discovered even after the bridge had been accepted an paid for.

From the foregoing remarks it may appear that I have taken sides wit the public against the highway bridge builders of the country. This is no my intention by any means. It may not be amiss to state that I have ha an experience in building bridges in the West that covers a period of eightee years, and have in that time come in contact with a great variety of publi officials, and while I have many pleasant recollections of honorable and fai treatment from this class, I have also many of the opposite.

That close and niggardly dealing with contractors by the public occur in many instances is a fact. That favoritism and prejudice have cheate many a contractor out of his just dues after being invited to bid on the wor is another fact. That the unfair treatment of responsible contractors b public officials was the principal cause that produced the method of busines known as pooling is another fact.

I believe it was my privilege to attend the first bridge lettings in th West where pools were formed, and the bidders present resorted to thi method as a means of self-protection, for the reason that we could discove in a majority of cases a predisposition on the part of the officials of variou counties to give their work to certain individuals, regardless of the claim or rights of the lowest responsible bidder. This would not have hurt s badly if they had sent for their favorite and given him their work to do, bu they would send out invitations to every bidder in the country that the could hear of, and after the bidders had gone to considerable expense i preparing, perhaps, special designs for the work and traveling two or three hundred miles to the place where the contract was to be let, they would find upon investigation that a certain company had the "inside track" and would get the work if it were possible for the officials to give it to them. This was not a very pleasant matter to discover, and naturally led the contractors to devise some means of getting their expenses out of the community who had trifled with them. This method of doing business served its purpose as long as it was not abused, but in time it degenerated, and the fruit it bore was the "scalper," and the modern bridge-letting illustrates how the business has been carried on up to 1887. At the present time pooling is rather the exception than the rule.

The professor proposes an association of highway bridge builders for the purpose of advancing the standard of work, and at the same time securing a fair remuneration for same. This is very desirable, but to form such an association is a difficult matter, owing to the jealousy existing between manufacturers, before mentioned. But should such a thing be attempted, it seems to me that the first order of business should be to compile and unanimously adopt a complete set of specifications that would cover every possible case in the highway bridge business. This being done it might not be possible to arrange the financial part of the matter, but if every company would agree to stand by the adopted specifications and put up a money forfeit as a guarantee of good faith, the bridges of the country would be well built, and contractors would certainly make as much money as they now do.

An association was formed a few years ago in which some twenty companies were interested; it was conducted in a first-class businesslike manner, and was a financial success to all parties who stood by their obligations. The bridges were very fairly built. One of the largest companies in the country started to abuse its privileges, and get all the contracts; others followed, and the association was dissolved at the expiration of the year, much to the regret of many companies who had endeavored to live up to their agreement.

I will not attempt to review or criticise the specifications in detail to any extent. That they are exhaustive, no one can deny. That they treat of every necessary condition and case in the detailing of iron highway structures is apparent, as far as my knowledge goes. That they are rather voluminous may be an objection raised by some bridge designers, but I look at such matters in the light that when a man undertakes to write on such a subject he does not want to leave anything out. And designers who may make use of these specifications can allow themselves such latitude as their individuality suggests, without violating mechanical laws to any great extent, and their bridges will be practically perfect.

In conclusion, I may add that thus far I have had in view the well-settled and comparatively independent parts of the Western country, whose people and traffic demand structures that are unquestionable in their capacity. But let us move farther west to the frontiers of civilization, if you please. Here we find new counties but lately organized. People are comparatively poor, but they have to travel, and the streams are in many cases just as important as in this part of the country. The people can ford these streams when the water is low, but do not want to run the risk of doing so when they have floods. They have a limited amount of money; they want a bridge. Materials are expensive on account of the distance from point of production. They call on an engineer to help them out by designing a bridge that can be built for the money they have. The engineer finds that he cannot do it and conform to standard specifications. What is he to do in such a case? It is quite a problem for him to solve, in which the element of chance plays the most important part; and the result to be determined is the difference between the chances of fording a dangerous stream or crossing a weak structure. I think the most of us would take the chances of crossing a weak structure, and would build it for them too. But in such cases the necessity of employing the skilled engineer who is master of his profession is apparent.

By W. L. Cowles.

I have read the specifications carefully, and am glad to say that, as a whole, they are calculated to insure work of the very best quality. They are very complete and cover all the details of design and construction fully. There are, however, a few points which, it appears to me, might be modified with profit. * * * * * *

With the exception of these points the specifications seem to me to be as peculiarly well adapted to their purpose, viz.: as a guide and a standard for those who are compelled to rely on the manufacturer through entire lack of knowledge on their own part as well as to those manufacturers themselves who are deficient in technical knowledge.

It is certainly very desirable that there should be a recognized standard, but still more necessary that there should be some authority to compel the use of the standard. It will be useless for engineers and bridge builders to agree upon a standard unless the buyers of bridges are obliged to purchase such only as conform to this standard. And this must be effected through the legislature directly, for the people are indifferent, trusting confidingly in those of their number who are selected to buy the bridges; and it is impossible to convince these latter that they can be deceived in the character of the structure procured—for is it not warranted?

But those having the power must be convinced of the necessity of appointing a state engineer, or of licensing a certain number of engineers, from one of whom a certificate of the quality of every bridge must be obtained and deposited with the state.

The confidence of county commissioners in themselves is illustrated by an incident which recently came under my notice. A city having a large number of bridges to build let contracts for some of them, and afterwards discovered that they had paid much more than they ought in the shape of pool. The commissioners claimed that profiting by experience they could not again be taken in in this way, and proceeded to let some more contracts. The result was that they again furnished a large amount of pool, but I doubt whether they are aware of the fact to-day.

As is very ably shown in the preliminary chapters of the "Specifications," all this would be avoided, and much money be saved to the purchasers, if excessive pooling on inferior bridges were abolished, as it would be naturally if all bidding were upon standard specifications, and the plans were subject to the inspection of a state engineer.

By Palmer C. Ricketts.

Any one who has had experience as an engineer in highway bridge building must recognize the force of the statements made in that pamphlet as to the quality of the majority of them and the questionable methods often employed to secure contracts.

As to improvements in the quality of these bridges, the only method, in my opinion, is the employment of competent engineers to supervise their design and construction; but when it is remembered that the number of railroad companies in this country which have their bridges so supervised is in the minority, the average highway commissioner can hardly be expected to be more wise.

When the use of questionable methods to secure contracts is considered, the old saying that "It takes two to make a bargain" should be remembered, and the consideration of a general method for the improvement of the morals of highway commissioners in connection with those of highway bridge builders would be appropriate.

In the opinion of the writer, competition will always prevent an efficient combination of any class of bridge builders, especially of highway bridge builders, as it has always prevented in the past efficient combinations of makers of unprotected articles which require for their manufacture comparatively inexpensive plants.

It is unnecessary to say that Mr. Waddell's specifications are first-rate, and that a bridge built under them would be a first-class structure.

By C. L. Strobel.

I am heartily in sympathy with any effort to improve the present practice of highway bridge construction, but I attach little importance to general specifications for the accomplishment of this end, and I think an association of highway bridge builders on the plan and for the purpose outlined impracticable.

I hold that good results cannot be obtained by the system now in vogue, of receiving bids accompanied by designs under general specifications. Under this system the plans are competitive, and it is left to the engineer in charge to decide which is the best plan for the least money. This is a difficult task. He is expected to throw out inferior plans, even though they do not conflict with the specifications, if he finds that these plans do not furnish the most suitable bridge or the best in ultimate economy. Even if it were easy to decide this question, the duty is a most disagreeable one. It requires considerable force of character, and it subjects the engineer to the suspicion of favoritism. If he holds a position of public trust, he cannot well afford to incur this. Assuming, however, that he is competent and ready to make the proper decision, has he the power to carry it into effect? Often not. In most cases the contractor whose bid is the lowest will get the work, even if his design is faulty. In other words, contractors receive no encouragement to design work to the best of their ability. They very seldom get more than thanks for their trouble.

Another difficulty is this: General specifications permit of different inte
pretations. By adopting certain refinements of calculation, such, for instan
as the consideration of secondary stresses, a bridge can be made to cost mu
more than the contractor estimated. Under the usual form of contract t
contractor depends upon the fairness of the engineer to a great extent as
what interpretation shall be placed upon the specifications. This is not bu
nesslike. To protect themselves in cases where engineers in charge a
known to be unreasonable and one-sided, contractors are sometimes oblig
to increase their prices to cover such contingencies, or they do not bid at a
If the engineer in charge is a bridge expert, and he ought to be, he will
competent to prepare his own specifications. He ought not only to do th
he ought also to prepare complete detail plans, and bids should be receiv
on these. Cities and counties should be encouraged to engage bridge expe
for this purpose. The question of compensation can be regulated in the sa
manner as done by architects. Rates should be established graded for d
ferent classes of work, and an understanding reached among engineers th
charges shall not be less than these rates, though they may be more, subj
to special agreement. The main reason why it is so difficult to get pay f
engineering work is that there are no established rates.

Lastly, some pressure must be brought to bear upon county comm
sioners, and this can only be done by the appointment of state enginee
whose duty it shall be to examine and report upon bridges, to whom plans
public works shall be sent for record, and who will be expected to recomme
to the legislature measures governing the construction of public works.

By Edwin Thacher.

Mr. Waddell's general specifications for highway bridges appear to
very complete, and if generally adopted would undoubtedly result in givi
us much better and safer bridges, as a rule, than we now have. It will n
be necessary to mention in detail the many good points in the specificatio
as I suppose the Engineers' Club is more desirous of obtaining criticisms th
commendations.

The greatest objection I have to the specifications is their great leng
occupying twenty-four pages of closely printed matter, while it appears to
that all necessary directions could be easily condensed into one-third of t
space. Unless a specification is reasonably brief a busy calculator cann
take time to read it understandingly, and many provisions are liable to
overlooked. I would prefer to have general directions sufficient to insure
first-class bridge and leave most of the details to the designer. * * *

A sample strain sheet and specifications would be as satisfactory to
expert as anything further, and if not submitted to an expert, it matte
little how much is shown. It should be sufficient if full detail drawings a
submitted for approval before work is commenced.

So long as time lasts many good engineers will honestly differ regardi
many points in a specification. Indeed, he would be a poor engineer w
had no preferences. It appears to me hardly possible for all to agree on a
one specification for highway bridges any more than has proved to be t
case for railroad bridges.

Almost any of the specifications used by bridge companies are safe enough, and those are the best which give the greatest strength for the least money. The trouble is not so much in the specifications as in seeing that they are faithfully carried out. This can be accomplished at a small expense by employing an expert of known ability to examine plans and strain sheets, and a competent inspector to examine sections, material and workmanship.

By A. J. Tullock.

I fully appreciate the difficulties we have to contend with in the present methods of letting contracts for public bridges. Owing to the fact that these lettings are in the hands of public officers, who are not familiar with the nature of the work to be done, nor able to discriminate as to the merits of proposals for doing it, I do not see any practical way of improving it, except by advocating the employment of proper consulting engineers, to take charge of such lettings.

If this can be accomplished, I would be very glad to co-operate with your Society, in any effort they see fit to make in that direction, and I think that most contractors, who have met with these difficulties, will gladly assist you.

By George L. Vose.

I hardly see how the proposed association is to be carried out. It is very easy to define what a good bridge is, and the good companies would be quite willing to agree to build nothing not up to the mark. Indeed, they have virtually done it already. But the trouble, it seems to me, will be to make the dishonest concerns that do so very large a part of this work, and who make their money by using an insufficient amount of poor material, agree to running the risk of losing their occupation. If the bad companies are forced to work up to good specifications their work will cost so much as to spoil their present profit, and they know it. If the bad companies cannot say to the town and county officers, "We will make you a cheaper bridge than the good companies will," their occupation will be gone. The bad companies care a good deal more about this kind of work than the good companies do, and I should think would be very apt to combine among themselves to keep it in their hands. I doubt very much if any organization can dictate to county commissioners what quality of bridges they shall build. The means used by the disreputable concerns to influence town and county officers are very potent. These officers, in most cases, don't want to be convinced, as far as I have known them. The fact that one concern offers to build their bridge for less money than another one is very apt to overbalance all other considerations. It is very hard to make a public officer understand that a factor of safety of two is not just as good as one of four. If one of these agents, with a good "gift of gab," tells them that the greatest possible load they can ever put on their bridge is not a half of what would break it down, they regard it as a wonderfully strong bridge, and as everything they need.

While I should welcome an association, or any other method of correcting the present evil, I hardly see how the plan of Professor Waddell is to effect the needed reform. There is, however, a power behind town and county officers, viz., public opinion; and, although the method is a slow one, I believe that a persistent endeavor to enlighten the public, and a timely sermon whenever a disaster furnishes a text, is about the only way to improve matters.

By De Volson Wood.

Having had no experience in "bridge letting," I am not qualified to enter minutely into the details of the subject, and will only make one or two brief observations.

The evils of a community or of society are not removed by merely changing a system, and much less by shifting an organization. Any particular evil may be greatly modified and substantially removed by either of those methods, but new evils are liable to spring up which may be more burdensome and more difficult to remove than the former. Evils grow out of the selfishness of men, and the desire to make profits will be just as strong with an "association of bridge builders" as without, and if such an organization becomes successful it may be used to secure an unjust profit.

The evils complained of in Chap. III., bridge letting, exist, and their excessive abuse lies partly in the fact that the commissioners who are to let the contract are ignorant of the "ways that are dark." I think that the evils complained of would be modified, if not entirely corrected, if commissioners were thoroughly acquainted with the fact that they are made to pay all those expenses in some way. For then some way would be devised by which they could be properly estimated and justly allowed. I am aware that even in this case there would be difficulty in managing the matter, but the "inevitable" would compel some kind of an arrangement. Would not the evils complained of be avoided if the commissioners would "buy" their bridges, as a man buys what he wants by going into the market? In this case the commissioners would go to the builders and would see the necessity of being paid for time and expenses, and it would save certain expenses of the builders.

Again, let the commissioners employ an engineer to make a design and specification, and get estimates on these of such builders as they might select. (Would such an engineer be so selfish as to tax the builder a commission?)

It would not remove the evil by the commissioners agreeing to pay a certain amount for these expenses, for the "bidders" would probably treat this as so much clear profit, and make their "pool" as before. It would probably work like the "tipping" system in England. Formerly the servants in hotels, etc., depended upon gifts from patrons, but the patrons proposed to the proprietor to include the servants' fee in their bill and give nothing to the servants, and they do now include servants' attendance in their bill;

but the custom of "tips" was so strong it was not banished, and now the traveler pays both the "bill" and "tips."

I trust that the agitation of this subject will result in a proper adjustment of these expenses, and so make them legitimate in form as well as in fact.

By Octave Chanute.

Of the number of remedies proposed for improvements in the present system of letting the construction of bridges, the one most advocated seems to be legislative action, and I will submit the following resolutions which have been suggested to me by this discussion.*

Upon the main question and the statement of facts there is no divergence of opinion among those we have heard from. The ignorance of the county commissioners is the main difficulty, and this we must accept as it is.

It is an irremediable trouble. They desire to save money, and fear public opinion, and the result is an unsafe structure. I believe there are within ten miles of this city a number of bridges which invite collapse.

The bridge builders would prefer to put up good bridges rather than poor ones, but their interest in the profits is such that there are many of them who will supply any demand, even if it be for a poor bridge. It follows, therefore, that any reform which is to be supported by the bridge companies must be compulsory on all of them. Of course, it is desirable that the county commissioners should employ experts to aid them in the inspection and selection of the plans submitted; but the effort to accomplish this has proven so futile that I believe it is useless. This adoption of any uniform specifications has also been impossible, although tried. In 1873, after a fatal bridge catastrophe in Illinois, the American Society of Civil Engineers appointed a committee to determine the best means of averting such disasters in the future. The committee was in existence four years and finally dissolved without reaching any conclusion, the various members having disagreed on numerous points. The public naturally concluded that if engineers could not describe accurately the difference between a good and a bad bridge, there probably was not very much difference anyway.

The objection to the appointment of a state officer to inspect bridges is that such office may become a political engine, and perhaps even defeat the object for which it was created; but this I think can be avoided by the adoption of suitable means for the selection of this officer.

Another objection is, that the creation of the office might tend to divide the responsibility, which is now entirely with the bridge company. The endangering of life under the present system ought to have much more consideration than the fact that the responsibility for accidents might be divided under another system. Another objection which might be raised is the cost of supporting the office of state bridge inspector. I think that the office might be made self-supporting by having suitable fees allowed the officer for bridges inspected.

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* These resolutions are given in the preface.

The discussion of the appointment of a state officer is in such shape now in various clubs that if the members of this club take action so as to bring the matter before the Legislature of this State next winter they will not be alone; for similar action will be taken simultaneously in other states, and the public discussion thus provoked would undoubtedly aid in the passage of the various acts.

By J. A. L. Waddell.

When advocating a very general discussion of my specifications, I did so with the hope of discovering points to be modified, corrected, or omitted in the second edition of the work, which edition will soon be issued. My desire has been gratified, and I think it will be found that the second edition will be an improvement upon the first. Of course it has been impossible for me to adopt the opinion of every engineer who has discussed the specifications, for no two engineers will agree exactly upon everything; besides if I tried to do so, the specifications would lose their individuality, and would of necessity conflict in different parts. Nevertheless, I have considered carefully each point that has been raised, adopting some suggestions, modifying and partially adopting others, and rejecting the remainder. . . .

In reply to Mr. Thacher's remarks I would state as follows:

1. That the specifications are made of unusual length for the reason that they are intended mainly as a safeguard against dishonesty and incompetency on the part of bidders. If commissioners were to state that they require bids upon these specifications and upon these only, and that they intend to submit all the designs to a competent engineer, highway bridge builders would soon become accustomed to designing bridges according to these specifications; and as the latter are very complete in detail, the consulting engineer, with very little labor, by beginning with the lowest bid and working upward, could readily determine which is the lowest bidder who complies with the specifications. Then, when working drawings are submitted, the engineer could hold the contractor strictly to specifications, for every detail is covered.

If for every bridge letting it were necessary to have an engineer prepare special specifications, a great deal of useless labor would be involved, and the majority of the specifications would be incomplete; for it costs money to get up specifications such as mine.

* * * * * *

It is very gratifying, indeed, to me to have the matter of reform in highway bridge building taken up in such a thorough and earnest manner by the Engineers' Club of Kansas City, and to see that the move which they are making is being followed by many of the local engineering societies throughout the country.

Concerted action on the part of these societies, tending toward legislative action, ought eventually, if continued long enough, to accomplish the much needed reform to which my efforts have for many years been devoted.

SOME DISPUTED POINTS

IN

RAILWAY BRIDGE DESIGNING.

INTRODUCTORY NOTES.

Some Disputed Points in Railway Bridge Designing was written in the winter of 1891-1892 and published in the *Transactions* of the American Society of Civil Engineers for February and March, 1892. The author wrote personal letters, soliciting criticism, to more than one hundred members of the society, and thus obtained an exceedingly thorough discussion of the paper. More than forty prominent engineers presented their views upon the various points relating to railway bridge design; consequently, the discussions contain the gist of the then current practice of the majority of America's leading bridge engineers.

Before this discussion each engineer conducted his practice in his own way and with only a limited knowledge of what other engineers were doing. The results of experiments and investigations were available only to those who made them and to a limited number of their acquaintances. New features of design were developed by two or more engineers independently at needless expense of thought and labor, and many unsatisfactory details and methods were continued from force of habit. The railway engineers prepared specifications which commonly required that all calculations for bridges be made with the engine diagram, and in place of determining which of several engines would produce stresses large enough to ensure a structure of ample capacity, they followed the penny-wise plan of requiring the bridge to be proportioned for the maximum stresses produced by two or more typical loadings. The absurdity of this procedure was made manifest both in Dr. Waddell's paper and in the discussions upon it. Specifications still demand that structures shall be calculated to carry typical train loads, but no railway engineer now specifies more than one; and so many roads have adopted the same loading that it is economical for the bridge companies to prepare diagrams, tables of moments and shears, and curves of equivalent loads, all of which greatly reduce the labor of computation.

The single-excess and the double-excess methods, which consisted of the employment of a uniform live load preceded by one or two additional or excess loads, have been entirely abandoned. The fatigue formulæ have almost become a thing of the past; in fact, only one prominent railroad uses one, and that is simplified in form. The consensus of opinion among able engineers regarding loads and methods of calculation and construction make it very unsafe for any engineer to resort to antiquated and unscientific practice.

Dr. Waddell's paper and the discussions it evoked contributed very largely to these results. The use of carbon steel has become universal, and that of nickel steel has begun; railway rolling stock has greatly increased, almost doubled, in weight; the use of impact formulæ has become common; but the fundamental principles of railway bridge design remain much as were stated by Dr. Waddell and his fellow bridge engineers twelve years since.

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SOME DISPUTED POINTS IN RAILWAY BRIDGE DESIGNING.

By J. A. L. Waddell, M. Am. Soc. C. E.

WITH DISCUSSION.

The object of this paper is to induce those members of the American Society of Civil Engineers who have made a special study of bridge superstructure to enter into an exhaustive discussion of a number of important points in bridge designing whereon authorities differ. The end to be attained by such discussion is the reconciliation of conflicting opinions, the simplification of bridge specifications, and the consequent improvement of designs. Such an object cannot, of course, be attained at once, but must be approached, so to speak, by an asymptotic curve.

That there are decided differences of opinion among experts as to what constitutes a good structure, and how a bridge should be proportioned, no one who has had much to do with bridge work will be disposed to deny. Some years ago there was hardly any uniformity whatever either in the detailing, or in the types and general outlines of bridges. To-day, however, by a process of elimination based upon the principle of the survival of the fittest, certain types of bridges for the different governing conditions have almost become standard, and the details of construction are gradually being reduced to a system. For instance, in railroad bridges, of which structures, by the way, this paper will treat exclusively, experience has shown that plate girder spans should be used up to a limit of ninety or one hundred feet, and that single intersection trusses with vertical intermediate and inclined end posts are preferable to other types of trusses. Nevertheless, certain well-known engineers are still employing the Whipple truss with its double system of cancellation; and pony truss, pin-connected bridges are still being built for short spans. Again, in respect to detailing, certain antiquated and very objectionable practices, such as the use of suspended floor beams with adjustable hangers, are, to a certain extent, still in vogue.

All this is sufficient reason for the opening of an extended discussion in which every one will be given an opportunity to put himself on record either in defense of peculiar personal practice or in objection to the practice of others; and it is the earnest wish of the writer that every prominent bridge specialist will take advantage of the opportunity offered, and thus do his share toward the attainment of a more satisfactory state of affairs in the specialty of bridge superstructure, and toward the placing of that specialty upon a still higher plane than it occupies to-day in the United States.

In order to systematize the contents of this paper it will be advisable to group as follows the disputed points, and to treat each group separately:

A. Live Loads.
B. Wind Pressure.
C. Styles and Proportions of Bridges.
D. Intensities of Working Stresses.
E. Combined Stresses.
F. Plate Girder Proportioning.
G. General Details of Construction.

In group *A* will be considered:

First.—The subject of Uniform Loads *vs.* Engine Concentrations, and *second,* The Proper Live Loads for Modern Bridge Specifications.

Several years ago two or three American engineers evolved independently the theory of engine concentrations for the finding of stresses in bridge members. No doubt these gentlemen at that time considered, and perhaps even yet think, that they were conferring a great boon upon the engineering profession; but, instead of this, they were really hampering it with a burden grievous to be borne. That such is the case every professional bridge computer, whose business it is day after day, month after month, and year after year, to calculate the stresses in bridge trusses, will readily and sadly acknowledge. The plea that this method is more accurate than the old one involving uniform loads, either with or without engine excesses at panel points, and that the calculations of stresses made thereby are just as simple and easy, is a fallacy. Of course, for any particular engine and train, the former method will give slightly more accurate results than will the latter. But there are never two trains alike in respect to amount and distribution of load, for the engines on any railroad vary greatly in weight and wheel distribution; and the weights on the cars are extremely irregular. It must be acknowledged, therefore, that all assumed loads for computing stresses in bridges are merely typical; consequently, when assuming a typical load, would it not be well to adopt one that will reduce the labor of the computer to a minimum, provided, of course, that it will give just as correct results as would one consisting of engine concentrations followed by a uniform car load?

That such an assumption is practicable the writer will show presently.

Now as to simplicity and ease of calculation: even in the most favorable case, viz., that where the chords are parallel, the panels of equal length, the structure rectangular, and the span comparatively short, it will take fully twice as much time to compute the stresses by concentrations as it will to find them by the old method. But when the span is long, the top chord broken, the panel lengths unequal, or the structure on a skew, the amount of labor involved by the concentration method is simply discouraging. How many engineers are there who make or have made a practice of computing the exact stresses in Whipple trusses by engine concentrations?

Not content with burdening computers to the extent of at least doubling their labor by enforced calculations involving engine concentrations, certain writers of bridge specifications have "added insult to injury" by specifying that each structure must be designed throughout for two and even three fundamentally different live loads, each involving a peculiar type of engine.

Let us for an instant consider the designing in competition of either a draw-span or a cantilever bridge according to one of these modern specifications and see what work there is involved. To begin with, there will be, say, six competing bridge companies, each employing for this work, on an average, two computers. Although these gentlemen may be firmly convinced that the requirements of the specifications in respect to live load are mere humbug and nonsense, and that they could obtain practically correct results with one-tenth of the amount of figuring by assuming equivalent uniformly distributed loads, they dare not shorten their work in this way for fear that some captious critic in checking their papers might find a variation in the stresses of 1 or 2 per cent.; consequently, all twelve of them set to work, with more or less ill grace, to calculate the exact maximum and sometimes also the exact minimum stress for each member of the bridge. It was discovered not long ago, that when the top chord is inclined to the horizontal, the maximum stresses do not occur with the same position of wheel loads as they would were the top chord horizontal. Hence it was sometimes necessary to make for each truss member three or four trials, each involving considerable figuring, before ascertaining the exact position of wheel load that would give absolutely the greatest stress.

Since then, however, the true theory of maximum stresses for engine concentrations in cases of inclined top chords has been worked up by one of our clever mathematicians, consequently it will no longer be necessary to use the "cut and try" method; but merely to employ the following simple little equation:

$$\text{Shear} = \left[\frac{M_r d}{l} - \frac{M_x(d+np)}{p}\right]\frac{1}{d+(n+1)p}$$

after having found, by trial, which wheel load should be over the panel point under consideration, by means of another pretty little equation, viz.:

$$\frac{P_n + wy_n}{N} \overset{=}{>} P_x \frac{d+np}{d}$$

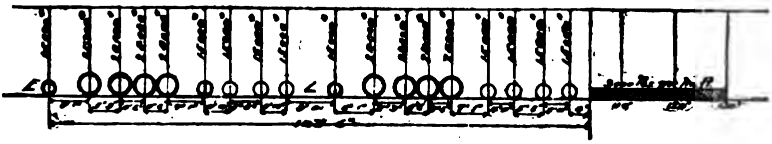
It must be borne in mind, too, that d has to be either calculated or scaled for each panel point, and that M will have to be computed every time that it is used, unless—which is highly improbable—a wheel load will come directly over the end of the span.

After having worked out all the maximum stresses by this method our twelve computers have accomplished only one-third of their task; for they must twice more attack the same problem but with different wheel concentrations.

After finding all of the live load stresses in the manner called for by the specifications, the remainder of the computations for the six designs will be of a comparatively simple character; hence let us suppose that all the papers of the six competing companies have been handed in. One company only can secure the contract; consequently, the work of at least ten men has been entirely wasted; and in fact there is often a strong probability of the work of all twelve being useless or at least unrewarded; for some other bridge company may have "an inside track" and build the bridge upon the set of papers which appears to be most satisfactory to the parties purchasing; or these parties may conclude that the proposed bridge is too expensive, and that they will build either a combination or a wooden structure. How much better off all six companies would have been had the calculations been made for an equivalent uniformly distributed live load, either with or without engine excesses, by the quick and elegant graphic method!

If one considers that the proper intensities of working stresses are to a great extent a matter of opinion, and that engineers often differ thereon as much as 20 per cent., he ought to be very quickly convinced that an endeavor to obtain stresses with extreme accuracy is nothing more nor less than hair splitting. But the best possible argument that anyone can advance against the use of engine diagrams in computing bridge stresses is a simple reference to Professor Eddy's elaborate paper entitled, "A New Graphical Solution of the Problem: What Position a Train of Concentrated Loads must have in order to cause the Greatest Stresses in any given part of a Bridge Truss or Girder," published in the *Transactions* of the American Society of Civil Engineers for May, 1890. Ye gods! what a mass of complicated mathematical formulæ that paper contains, and all to settle such a trivial little point! It needed not such an elaborate investigation as this to attest to Professor Eddy's great mathematical ability, consequently it seems a pity to have wasted so much valuable time. However, it may not prove to be time wasted after all; for Professor Eddy's paper may be the means of proving to the profession that in computing stresses by engine diagrams and proportioning parts by assumed intensities which do not provide adequately for the effect of impact, they have been "straining at a gnat and swallowing a camel."

In order to demonstrate the writer's assertion that practically exact stresses can be found by the assumption of equivalent uniformly distributed loads, let us take as a standard for comparison Mr. Theodore Cooper's engine diagram denominated "Class A," viz.,



as it is undoubtedly the diagram that has been most widely used since calculations by means of such diagrams came into vogue. By its use the bending moments and shears in the following tables have been calculated.

Those for stringers and plate girders have been computed for span lengths varying by 2½ feet up to a length of 25 feet, by 5 feet between the limits of 25 and 60 feet, and by 10 feet between 60 and 100 feet. In the case of truss spans, the smallest length has been taken equal to 100 feet, and the greatest equal to 300 feet, the intermediate spans varying in length by 50 feet; all of which is merely for convenience. For the same reason a single panel length (25 feet) has been adopted for all cases, and the chords have been assumed to be parallel and the trusses to be of the simple Pratt type. Although these conditions would not all be realized in modern practice, the assumptions cannot in any way vitiate the results of the investigation.

It will be observed that there are but two cases of loading to be used in the proposed simple method of making computations, viz., equivalent uniformly distributed loads for the chords and webs of all girders and trusses, and an additional load for testing the shearing resistance of the webs of plate girders at the ends of the spans. In reality the last load will be found to be needed only in cases of very shallow girders; consequently, we may say that the proposed method for all cases of ordinary practice reduces to the use of equivalent uniformly distributed live loads. That these equivalent loads can be used in finding the reactions or concentration over floor beams, the writer has just ascertained while preparing a summary of the results of the calculations that were made in compiling the tables in this paper.

The rule for finding a floor beam concentration is to multiply the equivalent uniformly distributed live load per lineal foot for a span of two panel lengths by the length of one panel. If the equivalent load was determined for the mid span bending moment, the result will be mathematically correct; but if it were determined for the absolutely greatest bending moment at any part of the span, the result will give a very small error on the side of safety.

That the principle involved was unknown to the engineering profession only two years since is evident from a perusal of Mr. Theodore Cooper's paper on "American Railroad Bridges," published in the July, 1889, number of the *Transactions* of the American Society of Civil Engineers; for on page 27 he says: "To represent the action of a train load properly by this method, we should need four different series of equivalent loads, all varying for each span.

"The apparent simplicity, therefore, of using equivalent uniform loads for proportioning our structures is a fallacious one; when applied to partial loads it becomes far more confusing and untrustworthy.

"The old method of computing strains by use of panel loads and equivalent uniform loads (and too often using only the one derived from the moments) has gradually given way to a system much simpler, more accurate, and also as easy of application."

Again, referring to the table at the top of page 26 of the same paper, drawing lines from the loads in the "Double Shear" column to the loads for twice their span lengths in the "Moment" column, and allowing for slight inaccuracies of calculation, or for the fact that the absolute maximum moments rather than moments at mid span were adopted in computing, what do we find? Not a confirmation of the mathematical theory herein given, for mathematical work needs no confirmation; but a sure proof that not one of us at that time knew the existence of the principle that will be demonstrated presently.

Referring to the quotation from Mr. Cooper's paper, it can be concluded that that gentleman is not only strongly in favor of the continued use of engine diagrams, but, also, that he is just as strongly opposed to the use of equivalent uniform loads. Consequently it is fair to presume that, after reading what precedes and follows this, he will give the matter a thorough discussion.

The following is a mathematical proof of the rule previously stated, and it is so simple that the writer is amazed that the principle was not discovered long ago:

Let P be any load, L the double panel length, x the distance from the nearer end of the span to the point of application of P, R the reaction or concentration over floor beam, and w the equivalent uniformly distributed load per lineal foot of span that will produce at the middle of the span the same bending moment as that due to P.

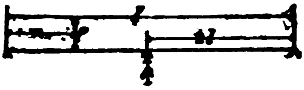


FIG. 1.

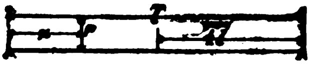


FIG. 2.

In Fig. 1 we have $R = \frac{2\,Px}{l}$ .... Eq. 1.

In Fig. 2 we have the moment at mid span $M = \frac{Px}{2}$

Equating this to the moment at the same point caused by the equivalent uniformly distributed load, we have

$$\frac{Px}{2} = \frac{1}{8}\,w\,l^2, \therefore w = \frac{4\,Px}{l^2}$$

Now multiplying w by the panel length, we have

$$\frac{1}{2}\,wl = \frac{l}{2} \cdot \frac{4\,Px}{l^2} = \frac{2\,Px}{l} \text{ .... Eq. 2.}$$

Comparing equations 1 and 2, we have $R = \frac{1}{2}\,wl$.

Now, as this is true for any single load, it holds good for any summation of loads, consequently the statement is proved.

To the writer's assistants, Mr. A. C. Stites, Assoc. Mem. Am. Soc. C. E., and Mr. Lee Treadwell, Jun. Am. Soc. C. E., is due the credit for making the numerical calculations before referred to and upon which the treatment of this whole subject of equivalent loads *vs.* engine concentrations is based. These gentlemen figured independently while some 300 miles apart, then compared results; consequently their results can be accepted as reliable.

EQUIVALENT UNIFORMLY DISTRIBUTED LIVE LOADS FOR PLATE GIRDER SPANS, COMPUTED FOR THE GREATEST BENDING MOMENT AT ANY POINT OF SPAN.

Span.	Equivalent Uniform Load.	Span.	Equivalent Uniform Load.
15 feet.	5 760 pounds.	45 feet.	3 995 pounds.
17½ "	5 407 "	50 "	3 860 "
20 "	5 040 "	55 "	3 726 "
22½ "	4 993 "	60 "	3 652 "
25 "	4 804 "	70 "	3 490 "
30 "	4 573 "	80 "	3 379 "
35 "	4 327 "	90 "	3 310 "
40 "	4 164 "	100 "	3 226 "

It is not necessary to prove here that such a table as the foregoing can be used legitimately in designing plate girder spans, for the reason that for five years past bridge computers have been using Thacher's tables of equivalent uniformly distributed live loads in plate girder designing, even if they have not been able to use them in computing stresses in trusses.

It may be possible that if the parabola of moments due to the equivalent uniform load, and a number of moments from concentrations at intermediate points, were platted on the same sheet, some of the latter would pass a trifle outside of the curve; but if so, this would cut no figure, because the maximum bending moment is in most cases the quantity sought in proportioning such structures; and in determining lengths for cover plates, a good designer will always add 2 or 3 feet to the length required by theory. The moment parabola referred to affords a very expeditious method of ascertaining the proper lengths of cover plates.

If we plot on cross-section paper the loads given in the table, and draw, as nearly as is practicable, a shapely curve through the points indicating the loads, we shall find that one or two of the points will not lie therein. This is due to some peculiar relation between the wheel spacing and the span length, and would not occur for the same span with the slightly different wheel spacing of some other similar locomotive; consequently, it would be proper, in preparing tables of equivalent uniformly distributed loads for actual use, to ignore such variations from uniformity and fill out the table from the ordinates to the curve.

A strong point that can be raised in favor of using equivalent uniformly distributed loads for finding bending moments in plate girder spans is that the ordinary engine diagram cannot be employed, for the reason that the greatest bending will nearly always occur when some of the wheels at the head of the train have passed off the span. In consequence one would either need to have at hand a moment diagram with each wheel leading in turn for each standard loading, or would have to discard all diagrams and make a special investigation of moments for each case as it arises, determining each time by experience or by trial which of several wheels placed at mid span will give the greatest moment. It is the latter method that the writer has used for years when forced into figuring by the concentration method because of competition.

As we have been dealing thus far with plate girder spans exclusively, we will now treat of the end shears on these before passing to trusses. Investigation shows that the amount to be added to the half of the total uniform load on any span in order to equal approximately the end shear is given by the equation—

$$W = A + BL$$

where W is the additional load, L the span length, and A and B are constants that will differ for different engine and car loads.

For the engines used in these calculations $A = 8\,000$ and $B = 100$. In the following table are given the results of the calculations:

Span $= S$.	Uniform Load $= W$.	Half Load $= \frac{WS}{2}$.	Additional Load by Formula.	Summation.	Calculated End Shear	Percentage of Variation.
15-foot...	5 760	43 200	9 500	52 700	50 880	3.5 Safety.
17½ " ...	5 407	47 311	9 750	57 061	57 325	0.5 Danger.
20 " ...	5 040	50 400	10 000	60 400	62 160	2.8 Danger.
22½ " ...	4 993	56 177	10 250	66 427	65 920	0.8 Safety.
25 " ...	4 804	60 050	10 500	70 550	70 248	0.4 Safety.
30 " ...	4 573	68 595	11 000	79 595	77 427	2.8 Safety.
35 " ...	4 327	75 723	11 500	87 223	85 402	2.1 Safety.
40 " ...	4 164	83 280	12 000	95 280	93 129	2.3 Safety.
45 " ...	3 995	89 887	12 500	102 387	100 114	2.3 Safety.
50 " ...	3 860	96 500	13 000	109 500	106 843	2.5 Safety.
55 " ...	3 726	102 465	13 500	115 965	113 295	2.4 Safety.
60 " ...	3 654	109 620	14 000	123 620	119 930	3.1 Safety.
70 " ...	3 490	122 150	15 000	137 150	136 310	0.6 Safety.
80 " ...	3 379	135 160	16 000	151 160	153 307	1.4 Danger.
90 " ...	3 310	148 950	17 000	165 950	169 685	2.2 Danger.
100 " ...	3 226	161 300	18 000	179 300	185 622	3.4 Danger.

By consulting the last column it will be seen that the formula assumed will give in most cases a small error on the side of safety. It is really only in the spans exceeding 70 feet that the error is on the danger side, for the value of W in the 20-foot span would in practice be increased by the adoption of a uniform curve of loads, as before mentioned.

Moreover, the end shear on plate girder spans is by no means an important factor in designing, for two reasons, viz.:

First.—There is nearly always an excess of section in the web of a well proportioned plate girder.

Second.—The intensity of shearing stress is always taken very low, being 4 000 pounds for iron and 5 000 pounds for steel.

The main object in inserting the last table is to show that it is practicable to establish, for any system of live loads, a simple formula for determining readily within a small limit of error the end shears on plate girder spans.

Passing now to truss spans, the following table gives the uniformly distributed load at each panel point of each span considered, which will produce the same bending moment as will the loads for the engine diagram. The averages are for the loads at all the panel points of a span, not the averages of those given in the table.

Panel Point.	100-foot Span.	150-foot Span.	200-foot Span.	250-foot Span	300-foot Span
No. 1	3 383	3 283	3 220	3 179	3 151
" 2	3 157	3 145	3 120	3 098	3 083
" 3	....	3 207	3 137	3 116	3 094
" 4	....	....	3 106	3 084	3 068
" 5	....	....	....	3 056	3 047
" 6	....	....	....	....	3 043
Average	3 308	3 215	3 151	3 112	3 085
Greatest Safety Error by using the Average	4.77%	2.23%	1.45%	1.83%	1.38%
Greatest Danger Error by using the Average	2.21%	2.07%	2.14%	2.10%	2.09%

It will be observed that the greatest error on the side of danger in any span is very little over 2 per cent., and that with the exception of the 100-foot span the greatest error on the side of safety is a little less than 2 per cent. The fact that the uniform load gives in general a small error on the side of safety for the chord members, except at the ends of span, is a good feature; because by placing cars ahead of the locomotives, greater chord stresses can often be found than those obtained by the use of the ordinary engine diagram.

As for the 2 per cent. error on the side of danger at the ends of span, it will cut but little figure even if it really affect the sections, which it generally will not, because in single track bridges the two panels of bottom chord at each end of span, being stiffened for wind pressure, have always a slight excess of metal; and the inclined end posts, being proportioned for bending, have a great excess of metal, as far as the direct stress is concerned.

Adopting for the web members the same uniform load as the average determined in the last table for the chords, and computing the web stresses from it, also computing the stresses for the same members by means of the engine diagram, we shall obtain the results given in the following table:

Span.	Member.	Shear in Pounds.		Percentage of Error.
		By Diagram.	By Uniform Load.	
100-foot ..	End Post	126 881	124 050	2.23 Danger.
	First M. Diagonal	59 429	62 025	4.40 Safety.
	First Counter	17 247	20 675	19.9 Safety.
150-foot ..	End Post	205 285	200 745	2.21 Danger.
	First M. Diagonal	134 585	133 830	0.56 Danger.
	Second M. Diagonal	78 142	80 298	2.76 Safety.
	First Counter	36 576	40 149	9.77 Safety.
200-foot ..	End Post	281 874	275 716	2.18 Danger.
	First M. Diagonal	209 992	206 787	1.53 Danger.
	Second M. Diagonal	148 784	147 705	0.72 Danger.
	Third M. Diagonal	97 484	98 470	1.01 Safety.
	First Counter	55 768	59 082	5.94 Safety.
	Second Counter	26 220	29 541	12.66 Safety.
250-foot ..	End Post	357 668	349 875	2.18 Danger.
	First M. Diagonal	285 278	279 900	1.88 Danger.
	Second M. Diagonal	220 844	217 700	1.42 Danger.
	Third M. Diagonal	164 804	163 275	0.93 Danger.
	Fourth M. Diagonal	116 264	116 625	0.31 Safety.
	First Counter	75 887	77 750	2.45 Safety.
	Second Counter	43 645	46 650	6.85 Safety.
300-foot ..	End Post	433 260	424 182	2.10 Danger.
	First M. Diagonal	360 438	353 485	1.93 Danger.
	Second M. Diagonal	293 893	289 215	1.59 Danger.
	Third M. Diagonal	234 684	231 372	1.41 Danger.
	Fourth M. Diagonal	181 734	179 956	0.97 Danger.
	Fifth M. Diagonal	135 034	134 967	0.05 Danger.
	First Counter	95 206	96 405	1.26 Safety.
	Second Counter	62 431	64 270	2.95 Safety.

The results of this investigation cannot be considered anything but satisfactory, for the "Danger" percentages of error are all small (never exceeding 2¼ per cent.) and affect the heavier members, while the

"Safety" percentages of error affect principally the counters. Setting aside the consideration of the inclined end posts for the reason mentioned previously, we find that the uniform load stresses for main diagonals coincide very closely indeed with the engine diagram stresses for the same members, the variation being hardly worth mentioning. As for the counter stresses, impact and oftentimes adjustment render an error on the side of safety a very good thing. Moreover, the method of proportioning counters is very variable. Some computers deduct the dead load stress of the panel, and others do not, while every conscientious designer always adds something to the section required for small counters in order to provide for uncertainties.

In concluding the subject of Concentrated *vs.* Uniform Loads, the writer wishes to urge each engineer who discusses this paper to give his opinion concerning the advisability of continuing to use the present laborious method of computing stresses in railway bridges, or of abandoning it and adopting instead tables of equivalent uniformly distributed loads for certain standard locomotive and car loads, to be chosen by the profession and similar to those hereinafter indicated. Only an array of opinions of authorities will induce railroad engineers to depart from the established custom to such an extent as to specify uniform loads when calling for bids on their proposed bridges; and it is, undoubtedly, these gentlemen who keep up the fashion in bridge specifications after it has once been set by specialists.

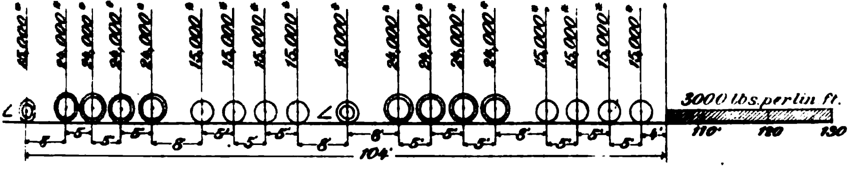
Taking up now the second division of "Group A," viz., "The Proper Live Loads for Modern Bridge Specifications," the writer would suggest the following (see plate XVI.):

Class Z of this series corresponds practically to Cooper's "Class A," and Class U to his "Lehigh Heavy Grade Engines." It will be observed, however, that there are but two wheel spacings employed, and that these are in even feet. This is merely for the sake of simplifying calculations; and any one who has for years struggled with Cooper's spacing of feet and odd inches when reduced to decimals of a foot will agree with the writer that the change is an improvement.

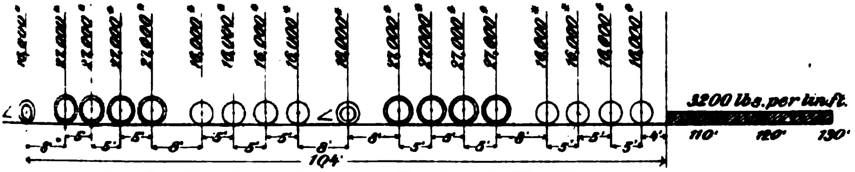
If the general sentiment of the profession prove to be in favor of the preceding standard loads, the writer will see that all of the necessary "equivalents" in accordance with his proposed system shall be calculated, tabulated, and presented to the American Society of Civil Engineers within a reasonable time. The regularity of increase of loads for the various proposed classes can be seen by inspection, therefore, if in the future heavier loads than the "Lehigh Heavy Grade Engine" with its car load of 4 000 pounds per foot be employed, it will be a simple matter to extend the series.

PLATE XVI
TRANS. AM. SOC. CIV. ENG'RS
VOL. XXVI. No. 522.
WADDELL ON
BRIDGE DESIGNING.

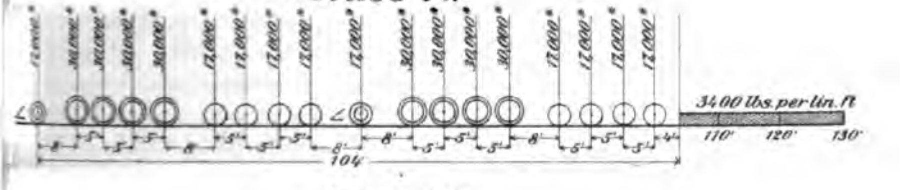
Class Z.



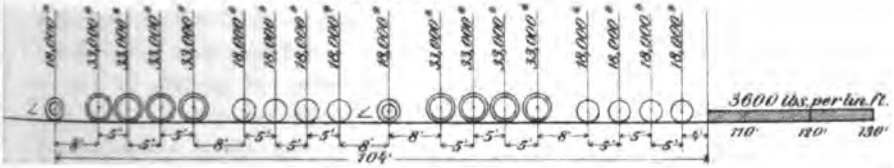
Class Y.



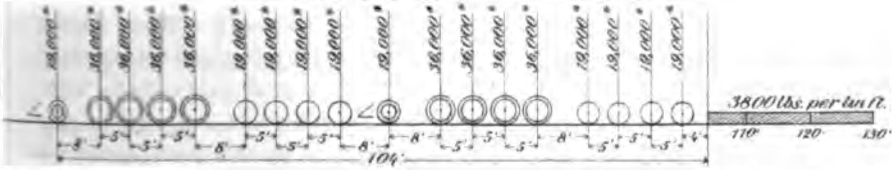
Class X.



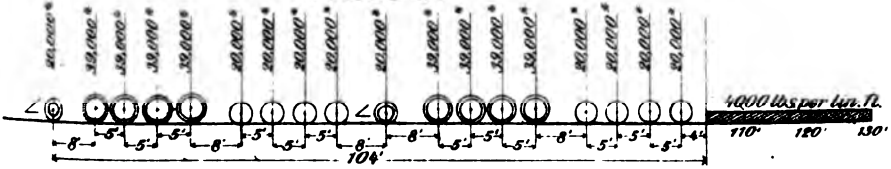
Class W.



Class V.



Class U.



Cooper's specifications provide alternative engine loads consisting of 100 000 pounds equally distributed on two pairs of drivers, 7 feet center to center, for his heaviest load, and reduced proportionately for his lighter loads. As these must be supposed to act without any other live load, it is evident that they can affect only certain bridge members for very short panels. But as the tendency of modern bridge designing is toward the use of longer and longer panels, it is evident that these alternative loads are unnecessary, unless it be for the wooden ties, in the proportioning of which judgment rather than figuring ought to govern. If we were to compare the moments found by Mr. Cooper's alternative live load for Class A with those obtained from our previously found equivalent uniformly distributed loads *after their adjustment by the curve*, we would see that there is only one case where the former would exceed the latter, and that by only 1.4 per cent., hence it is reasonable to conclude that, for spans and panels exceeding 15 feet, the alternative load is unnecessary.

Passing to "Group B," which relates to "Wind Pressure," we will divide the subject into two parts, viz., "Amounts" and "Effects." In respect to the former the practice has of late years changed somewhat, the tendency being to reduce the intensities specified and to provide more thoroughly for the effects. For instance, many of the older specifications called for a pressure of 50 pounds to the square foot of surface on both sides of the span, when the bridge is empty, while in fact nearly every structure designed according to those specifications would double up like a jack-knife under such a pressure. In most of the modern specifications, instead of stating the amount of wind pressure per square foot of surface, the amount per lineal foot for each chord is given, that for the loaded chord being 450 pounds, and that for the unloaded chord 150 pounds. For short spans this method is all right, in that it prevents the use of too light lateral rods and struts, but for long spans the amounts are too small. The writer has verified this statement a number of times lately in the designing of unusually long spans, more especially in structures which carry both railway and highway traffic. In one case, for a span of 500 feet, the total pressure, figured for an intensity of 30 pounds per square foot, ran as high as 900 pounds per lineal foot, and in another case, for a 560-foot span, figured for an intensity of only 25 pounds per square foot, it ran as high as 1 100 pounds per lineal foot. It is true that these spans were intended to carry both railway and highway loads; but even had they been intended for railway traffic only, the total pressure per lineal foot would have overrun considerably the 600 pounds ordinarily specified. In the writer's opinion, the best specification for wind pressure would embody both methods, using the standard 600 pounds as a minimum, and calling for intensities on the empty structures varying between 40 pounds for very short spans and viaducts and 25 pounds for very long spans, those on the loaded structures varying from 30 to 25 pounds.

In respect to areas opposed to wind pressure, it is the writer's practice to double the area of the vertical projection of one truss, deduct therefrom the area of the leeward web protected by the train, and add to the difference the area of the floor system found by multiplying the span length by the vertical distance from the top of the guard rail to the bottôm of the stringer. If the lower lateral diagonals be not protected by the windward chord or by the stringers, their area is to be included also.

Now as for the "Effects" of the specified wind loads, the most important of these are too often entirely ignored by computers, especially in competition; for it does not suffice to calculate the stresses in the lateral diagonals and stop there. In good practice the effects of the wind loads are followed from the points of application until the masonry is reached, and both the direct and indirect effects are considered. By direct effects are meant stresses which come directly from the loads, such, for instance, as the tension on the leeward bottom chord from the loads of the lower lateral system. By indirect effects are meant those which do not come so directly (and are, therefore, too often ignored), such, for instance, as the increase in the tension of the leeward bottom chord due to the load that is transferred from the windward to the leeward side in resisting the overturning moment of the wind loads of the upper lateral system, or the somewhat complicated wind stresses in the inclined end posts of through bridges. The latter subject will be treated under "Group E," but the former might as well be taken up here.

The amounts for the transferred load stresses cannot be determined with accuracy, but as they are large, it is not proper to ignore them for such a reason, because by making certain assumptions they can be found approximately. If, for instance, there were no upper lateral diagonals, and the wind loads on the top chords were therefore carried to the lower lateral system by means of the overhead transverse bracing, there would be transferred from the windward to the leeward truss at each panel point a load equal to the product of the wind load at the top chord panel point and the truss depth, divided by the perpendicular distance between trusses. The resulting tensions on the leeward bottom chord (which are the only stresses from this source that are of any importance) could be readily calculated, and would be found to increase from end to middle of span. But, again, if there were no overhead vertical bracing, the wind loads applied at the panel points of the top chord would be carried entirely by the upper lateral system to the upper ends of the inclined end posts, and thence down the same to the piers, producing a release of load on the windward pedestal and an increased load on the leeward pedestal. The latter, if the chords were parallel, would produce a tension on the leeward bottom chord that would be constant from end to end of span; or, if the top chord were broken, one that would decrease from end to middle of span.

Now, as in general the upper lateral system has, or ought to have, much more rigidity than the overhead transverse bracing, the probability is that most of the upper wind loads will travel by the former; so certain engineers, and of late the writer, among others, have been in the habit of assuming, for convenience, that they travel entirely in that way, and that in consequence the stresses from transferred loads in both leeward and windward bottom chords are constant from end to end of span, provided the top and bottom chords be parallel. The writer has gone a step farther by assuming that this holds good even when the top chord is broken; and, perhaps, here he is nearer the mark than in the case of parallel chords, for on one account the stresses tend to decrease from end to middle, and on another account they tend to increase in the same direction.

The released loads on the windward pedestals cause a decrease in the dead load tensions of the windward bottom chord, and this effect should be added invariably to the compressions in that chord from the wind loads of the lower lateral system when testing for reversing bottom chord stresses with empty structure. Too often this is ignored by computers, especially when competing for contracts.

We will now pass to "Group C," viz., "Styles and Proportions of Bridges." As before stated, these, by a process of elimination, are being gradually reduced to a system, although certain well-known engineers persist in adhering to antiquated types. Experience has shown that for spans up to 90 or 100 feet plate girders are the proper thing to use. They should, however, be built in one piece at the shops and never spliced in the field. This will limit the span for such structures to three car lengths, the weight during shipment being carried entirely by the outer cars, the intermediate one being an idler.

On account of the unavoidable uncertainty concerning stress distribution that exists in riveted connections, plate girders whenever they can be used are preferable to lattice girders. The latter, however, as through bridges, for single track spans between 100 feet and 150 feet in length, and for double track spans between 100 feet and 125 feet, are the proper style of structure to adopt. However, they should invariably be built upon the single cancellation principle instead of, as ordinarily, with several systems of intersection. The latter method is not only unscientific, but also extravagant in the use of metal; and the claims of its advocates that it is superior to the Warren type are imaginary and unfounded. Here is a fine opportunity to discuss the much-vexed question of multiple intersection *versus* single intersection riveted girders, and it is to be hoped that it will be taken advantage of by those interested in both sides of the topic.

It is evident from the preceding that the writer would rule out entirely the pony truss bridge. His reason for this is the uncertainty in computing the strength of the top chord. In the first place, its length as a strut is indeterminate; and in the second place, the side bracing, when attached to shallow floor beams, as is often likely to be the case, is liable to do more harm than good by forcing the panel points of the top chord out of line. The only satisfactory method of determining how to build good pony truss bridges would be to construct a number of them and load them to destruction, thus ascertain their weak points, and make, if practicable, the necessary corrections. But would not this be a case where "*le jeu n'en vaut pas la chandelle*"?

For spans exceeding 150 feet for single track bridges and 125 feet for double track bridges, the Pratt truss with its vertical intermediate and inclined end posts has proved to be the most satisfactory structure, although one of our prominent bridge engineers is advocating a truss with posts of varying inclination to the vertical. His principal claim for superiority for this truss is economy of material; but in the writer's opinion this is much more than offset by several inferior details, prominent among which is the suspended floor beam. It is hoped by the writer that the gentleman referred to, a good friend of his, by the way, will consider the foregoing as a sufficiently severe attack upon his pet truss to warrant him in bringing up the subject for a thorough discussion by the profession.

The principal objections to suspended floor beams are their lack of rigidity and their inefficiency as lower lateral struts. It has been whispered that riveted connections of floor beams to posts are not as perfect as they are held to be, but the writer has yet to hear of the first case of failure of the rivets in this connection when the beams were well proportioned and of the proper depth, although he has himself seen cases where extremely shallow and weak floor beams could not be retained to the post by any practicable means. He would like to hear the experience of other engineers on this point.

Beyond the limit of about 250 feet (more or less, according to the smaller or greater load carried) it is well to economize metal by adopting what is termed by some engineers the "Pettit" truss and by others the "subdivided Pratt truss," inclining the top chord as may seem advisable —in fact, the top chord may be inclined or broken to advantage in Pratt truss spans exceeding say 175 or 200 feet. In the Pettit truss the writer has become convinced that, in dividing the panels, it is much better to carry the intermediate panel load by a strut toward the pier than to take it by a tie toward the center of the span, even if the former method require, as it often will, more metal; because the rigidity of the truss as a whole is thereby increased, and the top chord sections are much more perfectly supported at mid length.

The inclination of the top chord to the horizontal is a feature that can be and is sometimes carried to excess. Its effect is undoubtedly to economize in metal; but at the same time its excessive use will throw too much work upon the top chord and leave very little to be done by the web, which, therefore, becomes light and vibratory. Again, with excessive curvature of top chord, the stresses in web diagonals are liable to reverse. If such reversion or tendency toward reversion be provided for adequately by stiffening the diagonals, it is true that the objection vanishes, but at the same time so does the economy. In the extreme case of the parabolic top chord, toward which some of our latest long spans approach closely, every panel would need counterbracing in order to transfer the advancing live load; and surely no well-posted engineer will claim that the parabolic truss bridge is a good structure to adopt.

It is the writer's practice when designing a bridge with inclined top chords to figure the advancing live load stresses for both tension and compression upon each web member in the truss from pedestal to pedestal, then, after allowing whatever seems advisable for impact, determine what diagonals will need stiffening and what will not. The percentage to be allowed for impact is a matter of judgment, and will depend largely upon the character and velocity of the advancing load.

The proper minimum distance between central planes of trusses for long through spans is still an undetermined point; some engineers make it one-twentieth and others one-eighteenth of the span. The writer is now inclined to adopt a middle course by calling it one-nineteenth of the span, although he once designed some 500 foot spans with a perpendicular distance between trusses of 25 feet. It is hoped that those engineers who think that the smaller limit will induce too much vibration will, in the discussion of this paper, give their reasons for so thinking. In case of deck structures, either the limit for the perpendicular distance between trusses must be increased or the truss depth must be decreased in comparison with the same dimensions for through bridges, on account of the greater overturning moment of the wind pressure; and for through spans of medium length, say 250 feet, the perpendicular distance between central planes of trusses should be much more than one-nineteenth of the span. The writer would suggest the following table for through spans of railway bridges:

Span.	Least Perpendicular Distance between Centers of Trusses.
250 feet and under.	18 feet.
300 " "	19 "
350 " "	21 "
400 " "	23 "
450 " "	25 "
500 " "	27 "
550 " "	29 "
600 " "	31 "

The writer is an earnest advocate of the increasing of clear roadways from 14 to 16 feet for single track through bridges and from 27 to 29 feet for double track through bridges. The extra 2 feet of width thus gained, together with a properly designed floor system and efficient protection and rerailing apparatus at each end of the bridge, would do away with fully 90 per cent. of the bridge accidents caused by derailments, and thus deprive the opponents of pin-connected bridges of their sole argument that is worthy of consideration.

The maximum allowable truss depth, except for draw bridges, in the writer's opinion, should never exceed three times the perpendicular distance between central planes of trusses; and when the extreme depth is used at mid-span it should be reduced toward the ends considerably.

For several years past the writer has held the opinion that in important bridges the lower lateral systems should be rigid, and he has now about come to the conclusion that an adjustable member is better out of any railway bridge than in it. However, he is not yet prepared to abandon entirely the use of adjustable members until such time as the profession will begin to agree with him substantially in this opinion.

In regard to the proper panel length for any truss bridge, the tendency of late years has been to increase this length for the purpose of saving metal not only in the eye-bars but in nearly all the other members of the structure; but, while saving metal, some designers have gone a little too far by using eye-bars too shallow for their lengths. Such proportions as 30 feet length and 4 inches depth are not unknown; but what the sag of these bars is the writer cannot say. Although not entirely guiltless himself in this particular, he has for several years been endeavoring to reform by adopting the following table, occasionally, however, departing from it slightly, but in all such cases compensating or endeavoring to compensate by the use of extra section in the member:

Unsupported Horizontal Length of Bar.	Minimum Depth of Bar.
15 feet.	2 inches.
16 "	2½ "
17 "	3 "
18 "	3½ "
20 "	4 "
22 "	4½ "
24 "	5 "
27 "	6 "
30 "	7 "
33 "	8 "
40 "	10 "

The theory has been advocated by a prominent engineer that the use of shallow bars for long panels can do no harm, for by the formation of a catenary in the bar the metal is not overstrained; but such a theory does not appear to the writer to be tenable. Long panels for wide bridges are all right, but for single track spans of short and medium lengths extraordinarily long panels cause the lateral diagonals to act with too small an inclination to the planes of the trusses, and thus lessen their power to check vibration.

In respect to the spacing of stringers there seems to be considerable difference of opinion among engineers. Some say that they should be placed exactly under the rails in order that the load may be applied directly, while others space them as much as 9 feet and even 10 feet apart so as to economize on metal in floor beams. If the former method be adopted, outer stringers should be used so as to support the ends of the ties in case of derailment. This, of course, increases the weight of metal, and is, therefore, objectionable, if a more economical and equally effective system can be designed. As a matter of fact, can any one point to a case where metal stringers have been injured by the bending down of the horizontal legs of inner upper flange angles, and if there be such a case, was there not some glaring weakness in the floor system proper? Statistics on this subject would be valuable.

For several years the writer has adopted the following floor system: Metal stringers spaced 8 feet between centers; pine ties, 8 x 12 inches on edge, and dapped 1 inch onto stringers, each tie being bolted at each end through the stringer flanges and outer guard timbers with ¾-inch bolts staggered in respect to the flange angles; outer guard timbers, 6 x 10 inches, or 8 x 10 inches, dapped 2 inches onto the ties, which are spaced, as nearly as may be, 13 inches between centers, leaving openings of 5 inches; and inner guards either of 5 x 4 x ½-inch angle iron, or of 6 x 6-inch timber dapped 2 inches onto the ties and faced on the sides next to the rails with 3 x 3 x ⅜-inch angle iron, screw-bolted to the timber, the guard timbers being bolted to alternate ties with ¾-inch bolts. Certain railroad engineers have objected to this system because of the difficulty of replacing ties. They say that only every third or fourth tie should be bolted, and that the bolts should not go through the stringer flanges, but should grip the same by one-sided heads. The writer's reply to this criticism is that the system was designed not to make it easy of replacement, but to make it difficult to break up or remove in case of derailment; for a floor system should be so built that it will carry a train entirely derailed across the structure without injury to the latter. The writer thinks that this floor system on bridges having 16 or 29 feet clear roadway, and provided with proper rerailing devices and collision piles in the embankment near the ends, will afford the best possible protection against failure of the structure by derailment.

If any one has a better floor system than this, let him describe it in his discussion and show why it is superior, after which the writer will be only too happy to abandon his system and adopt the better one.

Opinions differ concerning the use of pine and oak for floor timber. The writer's preference for the former is due to the fact that oak is unsatisfactory because of its warping and splitting. Moreover, when it gets old, dry-rot sets in and forms a punky material that is easily ignited. Good pine is decidedly superior to oak; but one should not economize on the depth of the ties when the stringers are much spread, for the strength of timber is usually overrated.

We will now pass to "Group D," viz., "Intensities of Working Stresses," and will take the bold step of assuming that in the near future the material for the metal portions of railway bridges will be exclusively steel. This step is warranted by the fact that to-day mild steel is practically as cheap as iron, and that it is fully as reliable.

There is no portion of bridge designing in which there is greater diversity of opinion among authorities than this matter of intensities of working stresses. For this there are two reasons: First, the problem of what is the relation between statically applied loads and the same loads applied with different velocities, is practically unsolved; second, the effect on metal of oft-repeated loads has been experimented upon very extensively, but not in a manner that makes the deductions from the experiments applicable to bridge designing.

The subject of the relation between statically and dynamically applied loads has for years been occupying the writer's mind; and at one time, when in Japan, he went so far as to design and build an apparatus for measuring the extensions of bridge members under loads. Unfortunately, either the design or the manufacture was defective (possibly both), for the instrument failed to give any record of value; and since then no opportunity has been found to continue the investigation. The French technical papers have lately stated that there has been designed in Europe an apparatus for making such measurements by means of water pressure of cylinders of widely varying diameters, and that the apparatus is a success. Here is a fine opening for a few energetic engineers and professors of civil engineering to make a series of experiments of the greatest value; and it is not unlikely that, were the experiments made under the auspices of the American Society of Civil Engineers, an appropriation to defray the expenses could be obtained from the United States Government. The results of a proper series of tests of this kind would be of incalculable value to the engineering profession, and, consequently, also to the general public. It is probable that the railroad companies would lend their assistance to the extent, at least, of furnishing trains and bridges for the experiments. The series of tests should cover spans of all kinds and lengths, and should be applied also to all the different members of the spans.

Now, as to the wearing effect of oft-repeated loads: a number of German scientists have devoted several years to an elaborate series of experiments upon the effect of loading and unloading quite rapidly test pieces of iron and steel beyond the elastic limit. The effect of these tests upon American bridge specifications has been to introduce a somewhat burdensome formula, which is generally of the form:

$$\text{Intensity} = \text{constant}\left(1 + \frac{\text{minimum stress}}{\text{maximum stress}}\right)$$

If the live loads on bridges were applied every two or three minutes, such a formula would be applicable; but in most cases the metal in bridges has time to recover itself between the applications of the live loads; consequently, the adoption of a "fatigue" formula would appear to be unnecessary, involving as it does the use of extra metal.

The adoption of a modification of this "fatigue" formula to cover the effects of both impact and fatigue is probably, in the present state of our knowledge, the best compromise that can be made; and the writer would consequently suggest that of

$$\text{Intensity} = \text{constant}\left(1 + \frac{1}{2} \cdot \frac{\text{minimum stress}}{\text{maximum stress}}\right)$$

This form of the equation (by no means original with the writer) accords very well with his ideas of what the extreme limits of stress on metal should be. It must be observed, though, that the "constant" in the equation must be changed for the different kinds of bridge members, as it would be obviously incorrect to make it the same for primary truss members and for the chords of long spans. Moreover, it is scarcely worth while to apply the formula to primary truss members, stringers, floor beams and plate-girder spans under say 50 feet in length; for in these the item of impact is so much more important than that of fatigue that, in the limited state of our knowledge, it is well to adopt intensities which we know by experience will be low enough.

The adoption of the formula involving the factor $1 + \frac{\text{min.}}{\text{max.}}$ is surely incorrect, for it implies that a live load is twice as destructive as a dead load. If this were so for one member, it would not be so for another; or, if it were true for short spans, it would not be true for long ones. Let us take, for instance, an extreme case and assume that there are, side by side, two very long duplicate suspension bridges whose cables are iron eye-bars. In one bridge, the dead load strains these bars 40 000 pounds per square inch, while in the other the dead load strains them to only 20 000 pounds; but once a day there passes slowly over the structure a live load that strains them 10 000 pounds more, making a maximum intensity of 30 000 pounds. Now, which of these structures would fail first? Surely it would be that which is loaded constantly to 40 000 pounds; but the theory would indicate that the two structures under the different loads are of the same strength. Some engineers have even been known to contend that were the live load in the second bridge increased so as to produce a tension of 20 000 pounds per square inch, making the maximum intensity 40 000 pounds, the other bridge would still be the one to fail first. This, perhaps, is an extreme view to take; but it would be interesting to try a similar experiment upon a small scale by loading a vertical tension member with a constant dead load that we know, if left on a certain length of time, will surely cause rupture, and loading other similar pieces periodically by loads applied and removed very gradually, producing a series of maximum intensities varying uniformly. If it be desired to obtain results for combined live and dead loads, certain of the test pieces could have dead loads attached that would differ uniformly. To obtain results with any pretension to authenticity, the test pieces should be made alike with the greatest care and of the most uniform metal obtainable; and there should be not less than three pieces used for each different kind of load. The writer would suggest that some energetic young professor of civil engineering, who has time to spare, undertake this series of experiments, and communicate the results to the American Society of Civil Engineers.

Mr. Cooper, in his specifications for both railway and highway bridges, effectively makes the broad statement that a live load in all cases is just twice as destructive as a dead load. If this be true for a railroad bridge where the moving load is applied rapidly and with impact, would it also be true in a highway bridge where the load is applied slowly and quietly? He may reply that he has increased the intensities for highway bridges; but this would be begging the question; for, surely, *the dead load* in a railway bridge is no more destructive than an equal dead load in a highway bridge.

The writer would suggest the following for intensities of working tensile stresses:

Bottom chords and main diagonals (eye-bars),

$$12\,000\left(1+\frac{1}{2}\cdot\frac{\text{minimum stress}}{\text{maximum stress}}\right)$$

Bottom chords and main diagonals (plates or shapes) net section,

$$11\,000\left(1+\frac{1}{2}\cdot\frac{\text{minimum stress}}{\text{maximum stress}}\right)$$

Long verticals (eye-bars)	10,000	pounds
“ “ (plates or shapes) net section	9 000	“
Short “ (eye-bars)	9 000	“
“ “ (plates or shapes) net section	8 000	“
Plate hangers	7 000	“
Bottom flanges of riveted cross-girders and stringers and longitudinal plate girders over 20 feet long	10 000	“
Bottom flanges of stringers and longitudinal plate girders of 20 feet length and less	9 000	“

The principal object in reducing the intensity for flanges of girders not exceeding 20 feet in length is to discourage the use of short panels.

It is proper to use the same formula for bottom chords and main diagonals, because the minimum stress in the former is the dead load stress, while in the latter it is the dead load stress less the live load stress that tends to put the diagonal in compression. When counter ties are used, of course there can be no such reversing stress in excess of the dead load stress, hence the minimum stress will be zero, and the proper intensity of working tensile strength will be 12 000 pounds for eye-bars and 11 000 pounds for plates and shapes. For counter rods, the writer, when he cannot avoid adopting them, still prefers to use iron, and to strain them 8 000 pounds to the square inch.

Some engineers contend that, *for steel,* tension members built of plates and shapes are as strong, per square inch of net section, as are eye-bars; but until ample experiments prove this to be a fact, the writer prefers to make a difference for the two cases, although not so great a difference as he would adopt were the metal iron. Discussion on this point would be valuable.

For top chords the intensity recommended would be

$$11\,000\left(1+\frac{1}{2}\cdot\frac{\text{minimum stress}}{\text{maximum stress}}\right)$$

unless the ratio of unsupported length to least radius of gyration exceed fifty, in which case the intensity given by the formula is to be multiplied by the quantity $\frac{50}{\text{ratio of } l \text{ to } r}$. In most cases of well-designed railway bridges the ratio of l and r is less than fifty. Some engineers are of the opinion that top and bottom chords can be strained alike, especially if a slightly higher grade of steel be adopted for the former, but the writer will be averse to this until experiments upon full-sized compression members prove it to be legitimate.

For inclined end posts the intensity of working stress should be found by the same formula as used for top chords; but in nearly every design for through bridges it will be found that the bending effect of the wind pressure will necessitate an increase of section. For vertical posts, which should always be hinged, the intensity can be found by the formula,

$$p = 12\,000 - 60\frac{l}{r}.$$

This formula was given to the writer some five years ago by Mr. Edwin Thacher, who established it in an eminently practical manner by plotting the results of a large number of experiments, inclosing the points by an oval and drawing an axis through the latter. The equation to this straight line, divided throughout by a certain factor for safety, will give the last equation. The writer wishes to protest here against the further use of $\frac{l^2}{r^2}$ in formulæ for compression members, for the reason that it involves unnecessary labor and gives results that are no more nearly correct than those obtained from formulæ involving $\frac{l}{r}$ to the first power. The general use of the second power is due to its having occurred in Euler's formula, which was established upon an assumption that does not hold good for compression members of bridges. Some engineers may contend that it is immaterial whether $\frac{l}{r}$ be used to the second or first power, as the results are always tabulated; but there are so many slightly different formulæ specified which involve $\frac{l^2}{r^2}$ that one often finds that the tables he has at hand will not apply.

For lateral struts, the ends of which should always be fixed, the formula will be

$$p = 17\,000 - 55\frac{l}{r}$$

This formula may appear to give too great intensities; but it will be found that the limiting sizes of sections and limiting ratio of length to least dimension, which are given in good specifications, will overrule the objection; and when designing the lateral systems of large and important bridges, the computer who tries it will become convinced that this formula is just what he needs.

In cases of very great wind pressures for long spans, where it takes a large amount of metal to provide for wind stresses, the writer considers it legitimate to adopt a double system of triangulation for the lateral system, and to assume that each half carries one-half of all the wind pressure allotted to the entire system; and in so doing he is not inconsistent, although condemning multiple systems for vertical trusses; because maximum wind loads are of rare occurrence, while the maximum loads for vertical trusses are liable to occur frequently.

Referring to the latest edition of Mr. Theodore Cooper's specifications, the writer wishes to take exception to two points relating to strut formulæ. First, the intensities specified for posts are excessive; for instance, in the case of a long span where, on account of the inclined top chords, the dead load stresses in posts are so small that we may here ignore them (if in fact they do not reverse), his formula for steel would be about $8\,400 - 48\frac{l}{r}$. If $\frac{l}{r}$ be assumed equal to 80, which is allowable, the intensity of working stress would be only 4 560 pounds. Surely this is too small for such a large and important member as a vertical post. Or, if we assume $\frac{l}{r} = 50$, the intensity will be 6 000 pounds, while according to Mr. Bouscaren's specifications it would be 12 000 pounds. Surely when two such high authorities differ to such an extent, some explanation is needed. The writer's proposed formula would give an intensity of 9 000 pounds, which is exactly a mean between the two.

Second, the writer considers it to be incorrect to treat a batter brace or inclined end post in the same way as a vertical post is treated; for the batter brace is in some extreme cases merely a continuation of the top chord, and in all cases resembles it in respect to stress and sectional area, therefore it ought to be treated as such. It is hoped that Mr. Cooper will explain in the discussion his reasons for specifying such peculiar intensities of working compressive stresses as those referred to.

Finally, a word in regard to the use of the formula for reversing stresses, viz., $p = \text{constant}\left(1 - \frac{1}{2} \cdot \frac{\text{minimum stress}}{\text{maximum stress}}\right)$

This should be employed where the reversion is of common occurrence, as in web diagonals, and not where it is unusual, as in the flanges of floor beams where the stresses are liable to be reversed once in a great while by highway loads carried on cantilever brackets.

We will now pass to "Group E," viz., "Combined Stresses," and will divide it into two parts: 1st, Longitudinal stresses only; and 2d, Co-existent longitudinal and bending stresses.

Part No. 1 relates principally to bottom chord proportioning when the wind stresses are taken into account. One authority stipulates for this, that when the wind stress exceeds one-quarter of the sum of the live load and dead load stresses, the section shall be increased until the total stress per square inch will not exceed by more than one-quarter the maximum fixed for the live and dead loads only. The writer would prefer, after figuring the direct and indirect wind stresses as explained previously in this paper, and adding them to the sum of the live load and dead load stresses, to use an intensity 40 per cent. greater than that adopted for the live and dead load stresses only, provided the intensity never exceed 21 000 pounds for eye-bars, or 19 000 pounds for tension members built of plates and shapes. It is better to take into account all possible stresses when finding the maximum total, and to use a high intensity, than to ignore certain important stresses and use a lower intensity.

Part No. 2 relates principally to the proportioning of batter braces or inclined end posts; and it is a peculiar fact that no railway bridge specification yet written begins to cover the ground of designing properly this important member of a through bridge; and, moreover, the matter is seldom given the importance it deserves, even in large bridges designed by our leading bridge companies and by expert engineers.

There are three vital considerations in the correct proportioning of batter braces, viz.:

A. What are all the direct stresses and how are they to be found?

B. What is the greatest bending moment, and how should it be computed?

C. What are the proper intensities to be used, and upon what should they be figured?

The answers to these questions are as follows:

A. Live load, dead load and transferred load stresses, the latter being computed as indicated previously in this paper.

B. The greatest bending moment is found by assuming a division (usually equal) of the total wind pressure upon the structure between the four pedestals, and multiplying the thrust on the leeward pedestal by the distance between the center of the end pin and the section of the batter brace under consideration. Some engineers, in order to reduce the bending moment thus found, which is undoubtedly very great, assume a fixedness of the batter brace at the pedestal, thus cutting down the length of the lever arm, and consequently the amount of the bending moment, by 50 per cent. Although the writer some seven years ago computed in this way, he is now convinced that the method is wrong; for the end of the piece cannot possibly be fixed or held in any way that even approaches fixedness. At the moving end of the span there is certainly enough play between the bottom of the pedestal and the holding down members, whatever they may be, to nullify all assumptions of rigidity; while at the other end of the span, even if there were no play in the end pin-hole, the anchor bolts and the details affected by the stresses therein are by no means strong enough to warrant one in assuming the connection to constitute a fixed end.

C. The intensity of working stress is the total intensity on the extreme fibre of the section considered, and is equal to the sum of the total direct stress divided by the sectional area of the member at the place considered, and the intensity of extreme fibre stress on the compression side, due to the bending moment of the horizontal reaction at the foot of the member. The value of this total intensity should lie between 20 000 pounds for short spans and 24 000 pounds for very long ones. Even these apparently high values will often make the sectional area of the batter brace appear excessive.

The most effective way to strengthen the batter brace against bending is to add metal in the form of heavy angle irons just outside of the webs of the built or rolled channels. A number of the latest Missouri River bridges, all built by the same engineer, show a quite unnecessary defect in the design for the reinforcement of the batter brace; for all of the reinforcing metal is placed upon the inside in the form of a built I beam, thus making the section of the member decidedly unsymmetrical, and weakening instead of strengthening it.

In one of these cases which the writer has checked, the addition of 16.85 square inches of section in the form of a built I beam *increases* the intensity of working stress for combined live and dead loads about 18 per cent.; while, if the same area had been added symmetrically, the intensity of working stress would have been *reduced* about 26 per cent. It is true that the member as it stands is all right for bending, even with the worst combinations of stresses, and the metal under live and dead load stresses is not dangerously overstrained; nevertheless, there seems to be no good reason for disposing of extra metal so unscientifically as to make it do more harm than good, when it could easily have been distributed advantageously. Possibly the reason is that if the extra metal were divided equally between the two sides of the member, the leeward batter brace would, for combined direct stress and bending, be strained about 10 per cent. higher than the windward batter brace with all of the metal on the inside; but even then the extreme fibre would still be strained within legitimate limits. Moreover, is it not better practice to overstrain metal once in a great while, say once in ten years, by 10 per cent. than to overstrain it 18 per cent. every time that the structure receives its full live load?

We will now pass to "Group F," viz., "Plate Girder Proportioning." In this matter there is quite a little difference of opinion among bridge designers, probably owing to the necessarily unsatisfactory character of all investigations concerning stress distribution in this style of girder. Plate girder proportioning amounts to but little more than rule-of-thumb practice; hence it would be well for us all to acknowledge the fact at once, and by a series of experiments to destruction, ascertain how satisfactory are our present methods of design, then, if necessary, modify them.

The questions of how the shear on the web travels, and how the stress on a flange distributes itself over the section, can never be determined analytically except upon assumptions that cannot be verified even approximately, nor can we tell by theoretical investigation what should be the proper thickness for a web; consequently, it would be well to drop these investigations at once and for all time, and content ourselves with ascertaining whether our present methods of proportioning will bear the searching investigation and criticism attendant on exhaustive experiments. In the writer's opinion any web of an economically designed plate girder, *if properly stiffened by angle irons*, will have sufficient sectional area as far as strength is concerned, consequently there is no use in adopting webs thicker than three-eighths of an inch for long, deep, single track girders, provided that that thickness give ample bearing for flange rivets near the ends of span, which in most cases it will.

As a matter of precaution, the writer is averse to making webs of stringers less than three-eighths of an inch thick, although he believes that five-sixteenths inch plate, when effectively stiffened and kept well painted, will do its work just as well. Does any one know of a case where the five-sixteenths inch web of a well-designed plate girder was the cause of even symptoms of failure? Some statistics on this point and on points of actual weakness of plate girders under traffic would be very interesting, and it is hoped that the discussion on this paper will bring such matters to light.

The clause in Mr. Cooper's specifications which stipulates that whenever practicable, one-half of the sectional area of any flange should lie in the two angle irons, is a very good one, and in the writer's opinion the number of cover plates used for a flange should be restricted to three, or preferably to two.

There is an important matter neglected in most railway bridge specifications, viz., the proportioning of end stiffeners where the plate girders rest on masonry or other supports. The intensity to use for the steel end stiffening angles should be 8 000 pounds; and the filling plates, if there be any, should not be counted upon as aiding the stiffeners. Both ends of such end stiffeners, and the upper ends of all intermediate stiffeners of deck girders, should be cut so as to bear against the horizontal legs of the flange angles. This is a point often overlooked in manufacturing.

There is some difference of opinion among experts as to the greatest allowable length of unsupported compression flanges of plate girders, Mr. Cooper placing it at thirty, and others as low as twenty times the width of the flange. The writer thinks that with the style of floor system described in this paper, where the track ties provide great lateral stiffness for the flanges, the limit of thirty is correct.

It is his firm opinion that the proper way to proportion the section of a plate girder for a given bending moment is to count in the web as aiding to resist bending. It surely does aid in resisting, so why not allow for its resistance? There is no need for going into burdensome calculations involving moment of inertia of cross-section, when the method of assuming that one-sixth of the area of the web is concentrated at the center of gravity of each flange will give almost identical results. Of course, if the web be counted in, the intensities of working stresses for the flanges will have to be decreased accordingly. While it is true that for girders of ordinary proportions it is immaterial whether the flange section be proportioned by one formula, ignoring the web, or by another equivalent formula involving it, it is evident that in girders of unusual proportions, for instance, very deep floor beams where the bending moments are comparatively small, the ignoring of the aid of the web in resisting bending causes a waste of metal in the flanges.

We will now pass to the next "group," and the last, viz., "Group G," which includes "General Details of Construction;" but on account of the large field that it covers, we will have to confine our attention to the salient points of design whereon engineers differ, taking up first those relating to general features and afterwards those that may be more properly termed "details."

The question as to how far the riveting of stringers to floor beams should be carried is still an undecided point. This method of construction has decidedly great advantages in respect to both rigidity and economy of material, but would be objectionable for very long spans for two reasons; first, the stringers have a tendency to do some of the work that belongs to the bottom chords, for which the connections of the former are unfit; and, second, there is a horizontal bending induced in the floor beams, especially in those near the ends of the span. The writer never hesitates about riveting stringers to beams in ordinary spans up to 175 feet in length, or in any draw span whatsoever; and he has lately concluded to adopt this construction for spans of any length by inserting sliding points in the floor system at distances of about 150 feet. Stringers riveted to beams really aid the bottom chords in resisting reversed stresses, but upon this fact the writer never relies, preferring to stiffen the bottom chords, although the practice of some bridge builders is to omit the stiffening.

The use of end floor beams for all spans is still an undetermined matter. The old practice was to let the stringers of the end panels bear upon the masonry, and to run a light strut between pedestals; but for several years the writer has invariably used end floor beams with stringers riveted to them, and is well satisfied with the results of the practice. The advantages of the detail are a homogeneous motion of contraction and expansion for all the metal in the structure with only two places for sliding or rolling motion, a greater rigidity of floor system in the end panels, and a very satisfactory end lower lateral strut. The only disadvantage is a slight one, viz., the necessity for using a little more metal.

The intersection *at a point* of all the axes of bridge members coming together at any panel point of a structure has for years been a desideratum, but as far as the writer knows has never been attained for any structure yet built. The writer, after seven years of trial, has at last solved the problem for large structures, and has applied the method to two or three large bridges that he is now preparing to build. The method, of course, could be applied to short and light spans also; but it would require an amount of extra metal that it does not seem advisable to employ, considering the fact that the objectionable results of eccentric connection can generally be provided for legitimately, either by straining the metal higher or by reinforcing. Unfortunately, however, the injurious effect of eccentric connections is too often ignored in bridge designs.

The connection of an end lower lateral diagonal to the pedestal plate instead of to the chord and end floor beam is a very faulty detail. To begin with, the connection is made generally a foot below the center line of the chord, producing a bending moment that, when expressed in inch pounds, seems enormous. At the fixed end of the bridge no special harm is done; but at the roller end the uniformity of the pressure on the rollers is seriously interfered with, and a bending moment is thrown upon the end diagonal, if it be a stiff member. In short, it is not a scientifically designed connection; and there is no need whatsoever for adopting it under any circumstances.

Of late years floor beams for large bridges have been designed with incomplete lower flanges for reasons with which all bridge builders are acquainted; but in such cases it is better to use an intermediate flange running the entire length of the beam rather than to carry the shear to the posts by patch-work. A few tests on full-sized specimens of floor beams with incomplete bottom flanges and patched ends would afford considerable information of value, and if the experiments were extended so as to show the effect on the strength of beams of beveling or fish-bellying their ends, the results would be still more valuable.

There is a very common connection for lateral rods that is quite faulty, yet is used at the present time. It is the one where the rod passes between the vertical legs of two short pieces of angle iron and through either a plate or another piece of angle iron for the adjusting nut to turn up against. It is faulty because the rivets connecting the angles to the main member are proportioned for a shear equal to the tension on the rod, while, in reality, there is a neglected bending moment equal in amount to the tension on the rod multiplied by the perpendicular distance between its axis and the main member. This bending moment must be resisted by an equal one, one of the forces of which is a direct tension on some of the rivets. If the length of the connecting angles were made sufficiently great, the detail would not be so objectionable; although rivets should not be subjected to direct tension. The tension, perhaps, might be considered *indirect* in that it comes from an induced bending moment; moreover, it may be made as small as we please by simply lengthening the angle irons.

The writer has designed and adopted a similar detail for making the end of a column truly fixed, running the anchor bolts two feet or more above the pedestal, each between two angle irons riveted to the member and through a very thick plate resting on top of the angle irons. In this case the tension on the rivets is a bagatelle. The ordinary fixed ends for columns, even when the anchor bolts are figured strong enough, are weak in detail on account of assumptions, made to save metal, which would never be realized were the column bent by the assumed transverse load. One favorable feature of the detail just described is that the pull from the anchor bolts is carried directly into the body of the column, passing by without straining the bed plate and its connecting angles and rivets.

Beam hangers with screw ends ought to be no longer countenanced, for they are in many respects inferior to plate hangers; and, in fact, suspended beams themselves should be ruled out, except for subdivided panels, in which case they should be stayed effectively against all motion. In the bridge specifications of the Atchison, Topeka and Santa Fé Railway Company (1889) there is a clause requiring that in double track bridges the floor beams be invariably suspended. The writer is desirous of knowing what is the reason for this requirement. If there be a good reason, the general practice of bridge designers should conform with the requirement; but if not, that clause of those specifications should be changed.

The minimum thickness of metal permitted in certain bridge specifications (filling plates, of course, excepted) is one-quarter inch; but in the writer's opinion this ought to be increased to five-sixteenths, and for all horizontal plates (that do not let the water drain off readily) to three-eighths of an inch. Metal that is exposed very much to smoke from locomotives, especially where the smoke can collect and hang, ought to have a thickness of three-eighths of an inch and be painted frequently.

In the writer's opinion, any mild or medium steel that will withstand the standard drift test, viz., the enlarging of a rivet hole 25 per cent. without cracking, will not require reaming of rivet holes.

The lengths of stay-plates for compression members are a matter of dispute among bridge builders, some requiring twice the lengths specified by others. The writer thinks that no hard and fast rule will answer, but that each stay-plate should have as many rivets to connect it to the main member as its importance of position demands. For instance, at the hips, the top chord and batter brace stay-plates should be long, while at the main intermediate panel points they should be shorter, and at sub-panel points they might be reduced to 12 inches in length, so as to provide four rivets in each line. As no experiments have ever been made upon the requisite sizes of stay-plates, there is nothing for the designer to do but to fall back on his past experience and common sense when proportioning these details.

Finally, there is an important item in detailing that seldom seems to receive proper attention: it is the effect of an eccentric stress upon a group of rivets. Designers do not appear to recognize the fact that there is, under such a condition, an immense bending moment that can only be resisted by an equal bending moment due to the shearing resistance of the rivets in a circular direction about the center of gravity of the group. How often we see a lower lateral rod of say 1¼ inch diameter connected to the flange of a floor beam by a pin through a plate that is attached to the angles by four seven-eighths inch rivets, the perpendicular distance of the center line of the lateral rod from the center of gravity of the group of rivets being, say, 6 inches, and that from the center of gravity to a rivet being, say, 3 inches. If T be the tension on the lateral rod, one-quarter T will be the *direct* shear on one rivet, and one-half T the *indirect* shear on same; and as one-quarter T is all that the rivet under the assumed conditions ought to stand, it is evident that the total shear on the rivet is three times as great as it ought to be. This is, of course, an extreme case, but it serves to demonstrate the point at issue.

The extent of this paper having far surpassed the limit set by the writer at the outset, he will now close with an earnest request that all those who are especially interested in bridge building discuss thoroughly not only the questions raised herein, but also other disputed points raised by themselves or by others in the discussion; for it is intended to submit all discussions for still further consideration until there shall be practically no more to be said on the entire subject.

DISCUSSION.

By Thomas H. Johnson, M. Am. Soc. C. E.

Mr. Waddell treats us to a bit of very pungent satire in his opening paragraph, when, after stating the object to be attained, he leaves us to infer, from his figurative reference to the asymptote, that he has no hope of accomplishing the object sought until the finite shall pass into the infinite, and "time shall be no more." And therein he is, no doubt, correct. So long as there are differences in the attendant conditions; so long as men see through their own eyes, instead of their neighbors'; so long as materials, and our knowledge of them are both in a state of evolution; so long as the engines, the cars and their lading, which our bridges are to support, are undergoing change—so long will men differ in opinion on many of the points raised in this paper.

To notice all the points raised by Mr. Waddell would practically amount to writing a full treatise on "Bridge Designing," for which I have neither time nor inclination. I will, therefore, only touch upon a few salient points. First of these is the subject of "Concentrated Loads vs. Uniform Loads." I have always been in favor of the concentration load method, because it involves more simplicity, greater accuracy and less labor. I am fully in accord with the quotation from Mr. Cooper which Mr. Waddell gives us on that subject; and while fully appreciating the beauty of his new method of finding the equivalent loads, it fails to convince me that the former method should be abandoned. The new method still requires separately determined uniform loads for moments, and for shear, each variable for different spans. The amount of labor necessary to calculate the equivalent loads, for each type of engine, would have served to make tables of moments and shears, for that engine loading, which would be far more serviceable than the uniform load, in reducing the labor of subsequent calculations; and the result would not vary "20 per cent." from the correct amount, as Mr. Waddell shows may be the case with the uniform load method.

Next, as to the types of loading proposed. Turning to Mr. Waddell's diagram, I note that he shows his heavy train loads with his heavy engine loads, and vice versa. The developments of the engine and train now in progress, and the future of which it is the bridge engineer's duty and aim to anticipate, are not being carried along on parallel lines. The growth of the engine results from the effort to increase the gross load hauled; the growth of the train load results from the effort to make the paying load a larger proportion of the gross load hauled. For instance, but a few years ago railroads were hauling 10-ton loads in cars weighing 8 tons; now they are hauling 30 and 40-ton loads in cars weighing 13 tons. And these cars, so loaded, go anywhere and everywhere; giving a condition of uniformity to the service on all roads that renders more than one, or at the most two types of train load, unnecessary. But with the engine the case is different. The type of engine used will depend upon the steepness of the grades to be overcome; and different roads, and different divisions of the same road, will require engines of different class; hence, all of the engine types shown will be needed. I would, therefore, suggest that the diagrams proposed be amended to show a uniform following load of 4,000 pounds per foot in all cases. The 40-ton car loads before alluded to bring the actual loads of the present day up to 3,000 pounds per foot, as a general every-day load; while special loads are frequently handled that far exceed this figure. It seems to me, therefore, that allowing for future development of the carrying capacity of the cars, 4,000 pounds is not too high a figure. I would suggest further that Mr. Waddell's engine diagrams will be more in accord with the actual dimensions which the engine builders are following if he reduces the driver spaces to 4 1-2 feet, instead of 5 feet, and increases the distance from rear drivers to tender wheel to 11 feet, leaving other dimensions as proposed. This will more nearly conform to actual fact, without sacrificing the simplicity aimed at.

I cannot agree with the author in his wholesale condemnation of the pony truss. There are certain situations in which this form of truss cannot well be dispensed with; and, notwithstanding the apparent ambiguity in the effective column length of the top chord, I have yet to see a pony truss bridge showing signs of failure on account of weakness in the top chord. I have known several such structures, some of which were built in the early days of iron bridges, and for light loads; and I have known them to show signs of failure in the floor beams, hangers, counters, etc., but never in the top chord. In the matter of subdivided panels, I must express myself in favor of carrying the intermediate panel load to the top panel points, which Mr. Waddell condemns. I fail, too, to see how the other method adds to the general stiffness of the truss as a whole, or how the mid-length of the top chord can be better supported than by the King post type of trussing. Furthermore, the form which Mr. Waddell advocates is open to the serious objection that in those panels having counters there can be no assurance that the load does not follow the counter instead of the brace. When the counter is in action from the advancing load it becomes certain that the load must follow the counter, because a tie and a strut, lying in the same axis, cannot both be in service at the same time.

Passing to group D, it strikes me that, after spending so much time pleading for uniform loads, for the express purpose, as alleged, of diminishing the drudgery of calculation, the author becomes inconsistent when he advocates a complex formula for determining unit stresses, with a so-called "constant" which must have different values for each class of truss members. The labor supposed to be saved by the uniform load will be more than lost in finding the unit stresses. And to what end? How much better will be the result than if we follow the simpler method of using a definite unit strain for each class of members, varied, if you please, by different unit strains for live load and for dead load? Touching upon the proper allowed stress for "tension members built of plates and shapes" calls to mind the growing practice of using built sections for the end panels of lower chords, and for the end suspender. The compression strains in these members are more or less remote contingencies, while the normal strains are those of tension. A due regard for the "eternal fitness of things" requires that these members present to the eye the forms of tension members, and the change from the eye-bar to the built form is an offense to the eye, which cannot be too severely condemned and frowned upon. Engineering structures are, as a rule, not æsthetic structures; but they have a beauty of their own, due partly to a certain grace of outline and proportion, but most of all because of a higher and more subtle beauty, born of an inherent expression of massive strength and fitness for their work. We can ill afford to sacrifice this beauty; and, so far as pin-connected trusses are concerned, I would make the allowed unit strain for built members in tension so low that the resulting quantity of metal required would more than balance the slight difference in cost as between angles and eye-bars, and thus remove all temptations to the use of this form of ugliness.

As to the unit strains on columns, it has been my lot to appear in print on that subject several times in the last few years, and I would not enter upon it now were it not that I believe I can add something to what has been said before. In Engineering News of December 22, 1888, I pointed out the fact that many of those who are adopting the straight line formula, $P = K - c\,\frac{l}{r}$, give the numerical constants arbitrary values without regard to the relation which should exist between them, which relation had been established in a paper on the subject, read by me at the Deer Park Convention, in 1885, and published in the Transactions of the Society for 1886. I now submit two plates, on which are plotted the lines representing all the straight line formulas now in use, which I have been able to collect—those for iron being on sheet No. 1, and those for steel on sheet No. 2. (See Plates XVII, XVIII.)

A glance at these diagrams would indicate that the profession at large has become convinced, not that the law of the column is correctly represented by a straight line, but that any straight line may represent that law. On Plate XVII, line No. 3 is for L. L. on chords, and line No. 8 is for initial strains on lateral struts, and both are taken from one and the same specification. Please note that these lines cross each other at $\frac{l}{r} = 50$, which means that for greater lengths than $\frac{l}{r} = 50$ he would require relatively more metal in a lateral strut than in a top chord. I cannot think that this was the author's meaning, but rather that it results from the determination of the value of c by "judgment" or "guess," rather than by the mathematical relation heretofore mentioned. On Plate XVIII, line No. 2 represents the equation for steel top chords, as used on the railroad lines with which the writer is connected. It has been established with due regard to the law of the column and correctly represents it. Line No. 16 represents the formulas which Mr. Waddell recommends, viz., 11,000 pounds up to $\frac{l}{r} = 50$, and $11{,}000 \times \frac{50}{\frac{l}{r}}$ for greater lengths. I trust Mr. Waddell will not take offense if I venture to point out that this formula is utterly without support in reason or experience, and is a purely arbitrary assumption in every particular. It is simply a guess and a very poor one at that, for, comparing the two lines on the diagram, it will be seen that Mr. Waddell's method gives results that at $\frac{l}{r} = 50$ are 27 per cent. too high, and at $\frac{l}{r} = 120$ are 16 per cent. too low. The diagrams speak for themselves and further comment thereon is unnecessary.

In the paper before referred to it was shown that the correct law of the column is represented by a straight line, tangent to the curve of Euler's equation. It was also shown, or stated, that this curve and its tangent

PLATE XVII
TRANS. AM. SOC. CIV. ENG'RS
VOL. XXVI. Nº 522.
JOHNSON ON
R. R. BRIDGE DESIGNING.

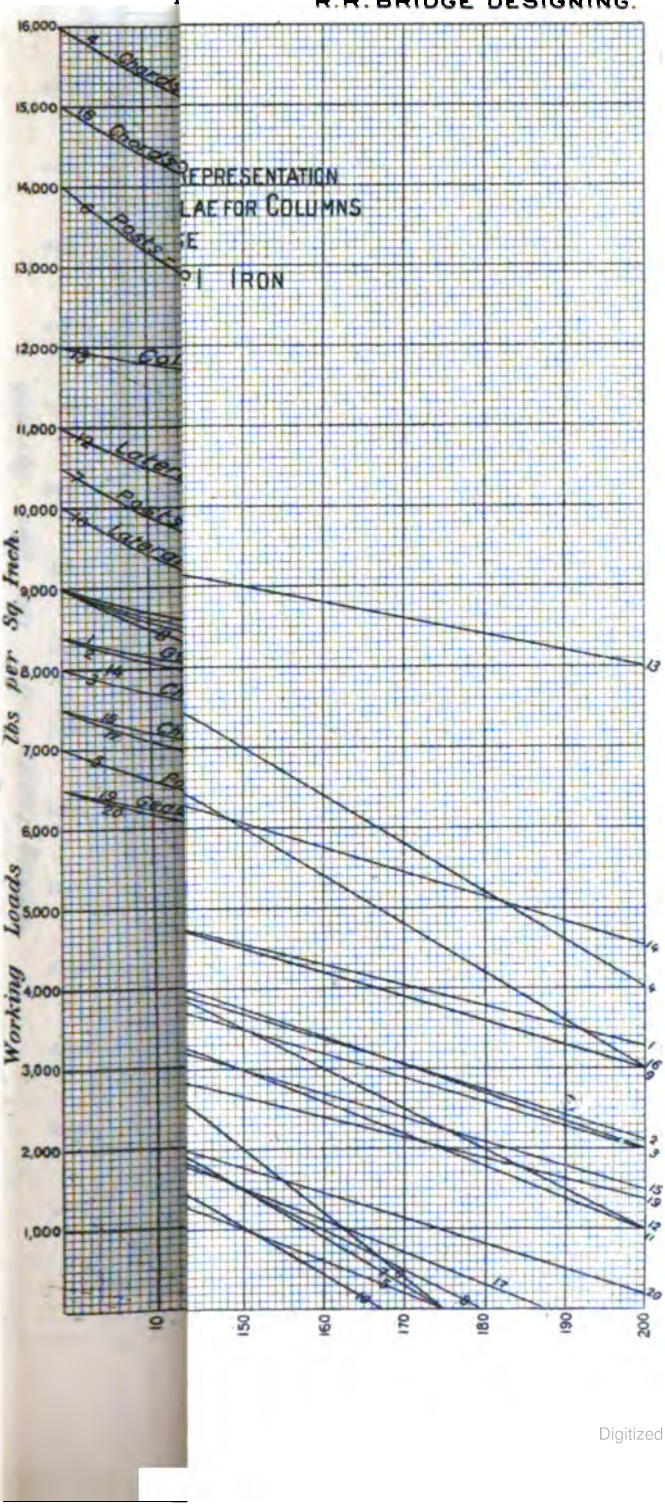
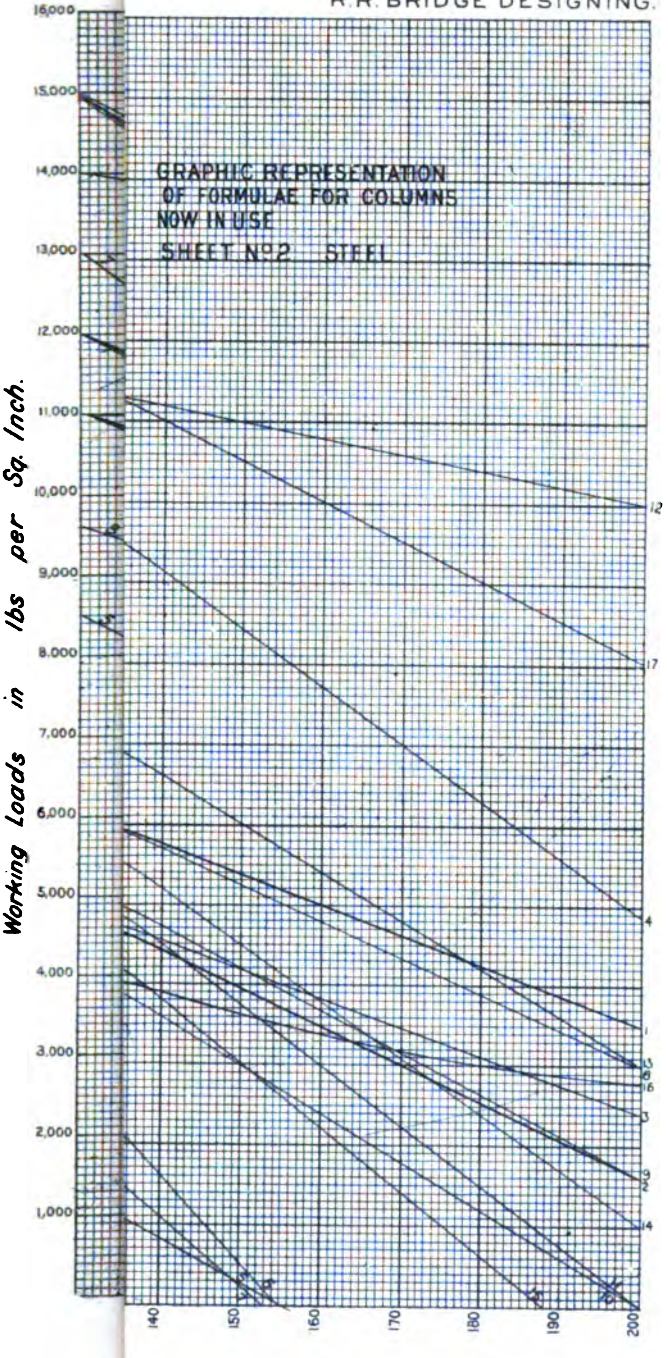


PLATE XVIII
TRANS. AM. SOC. CIV. ENGR'S
VOL. XXVI Nº 522
JOHNSON ON
R. R. BRIDGE DESIGNING.



possess the peculiar property that the ordinate at the point of tangency is always one-third of the ordinate at O of abscissas. I wish now to call especial attention to this property, as it contains the guiding principle which will enable us to find the proper value of c, for any assumed working strain value of K, in a simpler way than by the formula given in the original paper. In the working formulas, whatever value of K be assumed for the different classes of members, and kinds of stress, the value of c should be so taken that for $\frac{l}{r}$ = point of tangency, $P = \frac{1}{3} K$.

It was also shown that for different forms or end bearings the points of tangency are as follows:

	Iron.	Steel. 0.12 Carbon.
Square ends at $\frac{l}{r} =$	218	195
Hinged ends " $=$	178	159

To which I now add—

	Steel. 0.16 Carbon.
Square ends at $\frac{l}{r} =$	191
Hinged ends " $=$	156

Calling this distance to point of tangency m, then equation $P = K - c \frac{l}{r}$ becomes $P = K - c\,m$, when $\frac{l}{r} = m$.

But by the foregoing condition, we also have for that particular case, $P = \frac{1}{3} K$. Hence,

$$K - c\,m = \frac{K}{3}$$

$$\text{or,}\quad c\,m = \frac{2K}{3}$$

$$\text{From which}\qquad c = \frac{2\,K}{3\,m} \quad\text{(a)}$$

Giving to m successively the values just stated, we have the following values of c, in terms of K:

	Iron.	Steel 0.12.	Steel 0.16.
Square ends	$\frac{K}{326}$	$\frac{K}{292}$	$\frac{K}{286}$
Hinged ends	$\frac{K}{267}$	$\frac{K}{239}$	$\frac{K}{234}$

This will afford a simple, direct and ready method of fixing the proper value of c in any working formula for column strains. I give the formula for square ends and hinged ends both. It is my practice, however, to use only the hinged end formula for the compression members of bridges. There is no member in a pin-connected truss so fixed in direction at the ends as to warrant the use of the square end formula.

In regard to girder work, I wish to call attention to a practice which I believe is almost, if not quite, universal in the offices of the bridge companies. Notwithstanding the urgent advocacy of uniform loads, because the results are "near enough," they will carry calculation to ultra refinement in the weights of angles; making the top and bottom angle of a girder, floor beam or stringer to differ by 0.1 or 0.2 pounds per foot. I have even seen these weights written to two decimals. This practice becomes absurd, if we stop to consider that all that the rolling mills undertake to do is to get within $2\frac{1}{2}$ per cent. of the weights ordered; that is to say, in a 10-pound angle the allowed variation is 0.25 pound, and on a 25-pound angle it is 0.6 pound. These are the limits of accuracy in filling the order, and any greater nicety in the weights ordered is worse than useless, for it introduces shades of difference which cannot be detected by the shop foreman or the inspector with the calipers and foot-rule which they carry. I would like to see a clause in every bridge specification prohibiting the use of any weights of shape iron, except those corresponding to regular intervals of $\frac{1}{16}$ inch. It would then be possible to know that in assembling the right piece had gotten to the right place.

In "half through" plate girders, I notice that designers tend to the use of long panels with deep floor beams. This I regard as bad practice, because the lack of head room which prevents the use of deck girders also restricts the depth of floor; and, besides, the plate girder type always seems to me adapted to receiving small loads at many points, rather than large loads at few points. It will also be found, in most cases, that the greater concentration of loads on a few points results in larger flange strains than with the more uniform distribution due to shorter panels.

By T. C. Clarke, M. Am. Soc. C. E.

Mathematics is defined as the science which draws necessary conclusions. Such as the premises are, so will the conclusions be. Hence we should avoid the error of the young engineer, described by John Phoenix, who paced off the diameter of his circle, and then calculated its circumference to six places of decimals. Professor Waddell is doing good service in trying to show that the simpler method of uniform loads gives results as accurate as the assumption of loads headed by heavier engines can do, which is more complex to calculate. Certainly this is a matter of proof, and it can be shown whether he is right or wrong. In regard to usual pressures, it is a sad thing to reflect that a violent gale which would unroof houses, blow down chimneys and generally wreck any exposed structure presenting a solid surface will not injure any kind of steel or iron bridge unless already tottering to its fall like the old Tay bridge in Scotland. But, on the other hand, the most carefully designed steel bridge will be sheared in two by a tornado, as if made of rotten pine. We must take every possible precaution to give strength, by making the bridge wide enough and not too high in proportion to width, and then—trust in Providence that the tornado will go somewhere else.

For a wood floor, that described by Professor Waddell is good; but the time will come, we hope, when a steel bridge without a steel floor of plates and gravel filling will be looked upon as an imperfect structure, except in long spans where a reduction of speed generally takes place. The assumption that a live load is twice as destructive as a dead load is a safe one, and should not be changed until we get more light upon the subject. Engineers, in calling for tenders, would do better, instead of giving a formula, to work out the results, and give the maximum allowable strain upon each part of the bridge in detail, so much for top chords, so much for end posts, etc., etc. There would be no misunderstanding then. I agree with all the writer says about the proportioning of plate girders.

GENERAL DETAILS OF CONSTRUCTION.—The best rule I know of is to connect the chords, posts and diagonals with pins, and rivet all other connections. Also in spans of less than 150 feet, rivet all connections. The weak point in most bridges is the riveting of floor beams to posts. This should be carefully looked to, to see that the maximum shear is not exceeded. This is a very interesting and suggestive paper, and it is to be hoped that it will be the means of calling forth much useful information in the form of discussion by those actively engaged in designing bridges.

By George F. Swain, M. Am. Soc. C. E.

The writer has been accustomed for a number of years to compute bridges for a uniform load, together with a locomotive excess, believing that such an assumed load will give results that are practically as correct as those which may be obtained by the use of actual wheel loads. In a paper which he presented to this Society in 1887,* he referred to this matter, and advanced in favor of the use of uniform loads almost identically the same reasons which are now urged with such force by Mr. Waddell. At the same time, Mr. Waddell exaggerates very much the labor involved in computing with the actual loads, and his remarks on this point will not be concurred in by many engineers of experience, who have discovered the short cuts and simplifications that are possible in the use of the moment diagram. For instance, on page 9 of this paper, Mr. Waddell says: "A strong point that can be raised in favor of using equivalent uniformly distributed loads for finding bending moments in plate girder spans is that the ordinary engine diagram cannot be employed, for the reason that the greatest bending will nearly always occur when some of the wheels at the head of the train have passed off the span. In consequence, one would either need to have at hand a moment diagram with each wheel leading in turn for each standard loading, or would have to discard all diagrams and make a special investigation of moments for each case as it arises." Mr. Waddell has fallen into error here, for if some of the forward wheels pass off the span, this fact may be allowed for in a very simple and expeditious manner, and the advantageous use of the moment diagram is not in the least interfered with. The principal argument in favor of using uniform loads with a locomotive excess, it seems to me, is that it is simpler; and that by properly choosing the loads, the re-

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* "On the Calculation of the Stresses in Bridges for the Actual Concentrated Loads."—Transactions Am. Soc. C. E., July, 1887.

sults will be practically as correct as those obtained with a system of concentrated loads. The use, however, of a concentrated load system involving wheel spacings with fractions of an inch is a totally unnecessary waste of labor, and cannot be too strongly objected to. Most engineers will cordially agree with Mr. Waddell upon this point.

Mr. Waddell's remarks upon the subject of wind pressure are interesting and valuable. No doubt the actual amount of wind pressure to which bridges are subjected is very uncertain, but this is no excuse for neglecting to compute and to take due account of all the effects, having once decided what pressure per square foot to allow for.

The writer cannot agree with Mr. Waddell in his unqualified condemnation of double system riveted trusses. The general principle of adhering to structures in which the stresses are as nearly as possible determinate is undoubtedly sound, and will be conceded by most American engineers. No structure, however, not even the pin bridge with one web system, is perfectly determinate, on account of the continuity of the top chord, the friction on the pins, and other circumstances; and when, as in a riveted truss, the joints are firmly connected, and both chords are continuous, the amount of uncertainty in the stresses is quite considerable, and the secondary stresses very appreciable. Under these circumstances, which are well understood, the additional uncertainty introduced by using two systems instead of one is small in comparison, and the advantages of the double system certainly deserve consideration. These advantages are principally the simplification of the details of the connections—an advantage which will be fully appreciated by any one who has attempted to design a single system riveted truss of considerable span, and the further fact that the destruction of one web member of the truss does not necessarily mean the collapse of the span. The terms "imaginary" and "unfounded" will have to be applied to Mr. Waddell's claims in favor of the single system truss and his unqualified condemnation of anything else, until he advances arguments and facts instead of simple statements in favor of his position. While most engineers will probably prefer single system riveted trusses in general, they will admit that the use of double systems under certain circumstances is not without justification.

Neither can the writer agree with Mr. Waddell in his unqualified condemnation of suspended floor beams. The arguments on both sides of this question deserve consideration; and if it is objected that suspended floor beams lack rigidity, it may be replied that this objection may frequently be overcome, while the method of riveting the floor beams to the posts introduces objectionable features which cannot be remedied, namely, the bending of the posts, the twisting of the chords, and the consequent unequal distribution of stress upon the diagonal bars, the inside bars of any one diagonal carrying a greater load than the outside bars. Added to this is the fact that the upper rivets in the floor beam connection are exposed to tension. If Mr. Waddell considers that these objections are met by the statement that he has never heard of the failure of rivets in this connection, we may ask him if he has ever heard of any practical disadvantage arising from the use of a properly constructed plate hanger. No doubt suspended floor beams with adjustable hangers are objectionable, but a single plate hanger, riveted to the floor beam, transfers the load centrally to the pin, and when combined with proper details with reference to the lateral bracing, such a construction certainly has a great deal in its favor, and is not to be condemned without qualification.

The matter of the stresses in eye-bars due to their own weight is an interesting and important one, but there is not space to discuss it thoroughly here. The writer long ago came to the conclusion that the additional stress due to the weight was largely counterbalanced by the effect of the pull in the bar acting with a lever arm equal to the deflection. The precise condition of things may be found mathematically.

Mr. Waddell's floor system is a good one, though the writer much prefers to have the stringers under the rails, and safety stringers outside. The distance of the inside guard rails from the track rails, where re-railing devices are not used, is a matter regarding which there is much bad practice; and the writer has seen, on some important lines of railroad, these inside guard rails within 2 inches of the track rails. In such case they would be worse than useless, since a wheel could not run between the two rails, and even a 6-inch space, which would allow a wheel to enter, is not sufficient, since the opposite wheel would even then cramp the track rail, especially in the case of a narrow-gauged pair of wheels. With regard to the collision posts, the writer must confess that he doubts their value, and cannot but feel that they may, in many cases, do harm instead of good.

Mr. Waddell apparently considers the "fatigue formula" for determining dimensions to be unnecessary and burdensome, yet he proposes a form of it which is in principle the same thing. The difficulty which he encounters, in considering this matter, appears to arise from the fact that he does not separate the effect of impact from the effect of repeated stress. The matter of repeated stress is simply this: if a load of 55,000 pounds, applied gradually and once, is required to break a bar, then any less load will not break it, if applied once, and allowed to remain; but if the load is varied between, say, 45,000 and 30,000 pounds, rupture will finally occur; or if the variation is from 40,000 to 20,000 pounds, or from 30,000 pounds to zero, rupture will in time occur. Now, those who use the repeated stress formula believe that in each case, for a given ratio of maximum to minimum stress, the factor of safety should be allowed on the ultimate strength for this same ratio of maximum to minimum. That is to say, using the above figures simply for illustration, if the factor of safety is five we should allow:

11,000 pounds per square inch for a bar in which max. = min.
9,000 " " " " max. = 1.5 min.
8,000 " " " " max. = 2 min.
6,000 " " " " min. = 0.

These results are unquestioned, although the effect of time—both during the application of the load and between loads—has not, until very recently, been carefully studied. Now the effect of impact is a separate matter, and the writer can see no correct method of allowing for this except by adding a certain percentage to the live load stress, adding to this the dead load, and treating the whole as a dead load. If this method is used, all difficulty vanishes. The percentage to be added should be assumed by the engineer according to a sliding scale, using judgment and experience in default of accurate experiments; then the factor of safety for a dead load must be decided upon, and used on the ultimate strength according to one of the repeated stress formulas, or used on the elastic limit, to suit the opinion of the designer. Mr. Waddell's formula will not suit all cases, highway as well as railway bridges, simply because the impact is different in these cases. And, in this connection, the importance of using a sliding scale in varying the unit stresses may well be again urged. Surely it is unscientific to allow 10,000 pounds per square inch for bottom flanges of plate girders over 20 feet long, and 9,000 pounds when they are under 20 feet long. This practice will result in giving heavier flanges for a girder slightly under 20 feet in span than for a girder slightly over 20 feet span. And surely the allowable stress for chords in a truss 500 feet long could be greater than for chords in a truss 100 feet long, on account of the difference in impact, although by Mr. Waddell's formulas the same would be allowed in both cases. The writer may add here that personally he believes the use of a repeated stress formula unnecessary, on account of the fact that no load below the elastic limit will produce rupture of a sound bar, however often applied. He advocates using a factor of safety for dead load, based upon the elastic limit, and allowing for impact by a sliding scale of percentages.

Mr. Waddell advocates the straight line formula for posts, and protests against the use of $\frac{l^2}{r^2}$ for compression members, claiming that it involves unnecessary labor. The difference of labor between using the ordinary formula with $\frac{l^2}{r^2}$ and that with $\frac{l}{r}$ is very slight, and it may not be out of place to point out here that the straight line formula, such as $p = 12{,}000 - 60\frac{l}{r}$ is incorrect in form, and cannot possibly be a correct formula, though it may give results practically close enough. The correct principle to follow in deciding upon a formula for proportioning members would seem to be to find first the correct form for the formula, and then to determine the constants according to the results of experiments on materials. These constants will be subject to modification as our knowledge of the strength of materials increases, but the formula will retain the same form. To use a formula whose form is incorrect is a step towards empirical and rule-of-thumb methods, which Mr. Waddell and many others who advocate the straight line formula would in general be quick to deprecate.

A strut is exposed, in any cross-section, to a uniform compression over the entire area, equal to $\frac{\text{load}}{\text{area}} = \frac{P}{F}$, and to a bending moment due to the fact that the strut deflects and the load does not act along the axis, this axis being curved. The maximum fiber stress f will be the sum of the compression and of the bending stress, which last we may call s. Then,

$$f = \frac{P}{F} + s,$$

and must equal the allowable stress per square inch. Then we have,

$$\frac{P}{F} = f - s.$$

In the straight line formula,

$$\frac{P}{F} = 12{,}000 - 60\frac{l}{r}.$$

The reason why this formula is incorrect in form is that the term s is made constant, and independent of the load P. That is to say, the fiber stress, due to bending, produced by the load P is independent of that load, an obviously absurd statement. In the usual formula with $\frac{l^2}{r^2}$, s is made to vary with P, as it must, being equal to

$$\frac{P}{F} \cdot \frac{1}{a} \cdot \frac{l^2}{r^2}.$$

Then we obtain,

$$\frac{P}{F} = \frac{f}{1 + \frac{1}{a} \cdot \frac{l^2}{r^2}}.$$

The only argument that can be advanced in favor of the straight line formula is that it is slightly simpler. It is no more accurate, and is not as reliable when applied to cases beyond the range of actual experiment, because of its incorrect form, and there appears to the writer to be on the whole no sufficient justification for its use.

Mr. Waddell's formula for wind struts appears to be proposed because in most cases empirical rules will make it unnecessary to use it, and for other cases it is "just what the computer needs." Surely scientific method and a due consideration of the proper factor of safety should rule in deciding upon even a formula for wind struts. As regards the proportioning of inclined end posts for bending, due to wind pressure, it is certainly incorrect to assume that the post is hinged at its lower end, and that the moment at any point is that due to the total wind reaction acting at the foot of the post. Whether it is correct to assume the post as absolutely fixed at the bottom will depend upon the ratio between the wind pressure and the vertical load upon the bridge; but in most cases it is, in the writer's opinion, much more nearly correct to assume the end fixed than to assume it hinged. The writer cordially agrees with Mr. Waddell's remarks as to allowing, in plate girders, for the bending borne by the web. One point, however, Mr. Waddell does not refer to, namely, that where the web is not considered as resisting bending, the web splices are proportioned for the shear simply, and the number of rivets in such splices is often so small as to render it certain that those near the top and bottom are much overstrained by the bending. In the writer's opinion, every web splice should have two rows of rivets on each side, the rivets spaced about 3 inches apart vertically in each row.

Mr. Waddell's paper abounds in sensible remarks, which have not been referred to, and the principal points selected for discussion have naturally been those in which the writer's views differ from his.

By J. M. Johnson, M. Am. Soc. C. E.

The use of equivalent uniform loads in place of wheel concentration for the calculation of the stresses in bridge members would undoubtedly greatly lessen the labor of bridge computations, and, as Mr. Waddell points out, give results differing but slightly from those obtained by the method of wheel loads. I would be very much in favor of any plan having for its object the abolition of the various so-called standard engine loads, and the substitution of uniform loads equivalent to some such series of wheel concentrations as proposed by the author. However, if any uniform system of loading could be agreed upon by engineers, whether uniform loads or engine concentrations be adopted, a great step forward would be made, and the styles and proportions of bridges and general details of construction might safely be left to individual preference.

I imagine that substantial agreement among engineers can only be obtained upon the following points, viz.:

First.—The loads to which structures should be subjected.

Second.—Intensities of working stresses.

Third.—Kind and quality of material.

With these points definitely settled and adopted, a partial uniformity of detailing might in time be brought about, although it is probable that personal bias and differences of shop practice will continue largely to influence such matters.

The loads prepared by Mr. Waddell seem suitable, and I would suggest no change. Although the author has developed a set of working stresses, I fail to find in his paper a statement of the ultimate strength and other physical data concerning the material proposed for general use, and in consequence the formulas could not well be criticised. In my judgment all specifications should contain requirements, stating under what conditions both iron and steel could be used, leaving it to the engineer to determine which would be the more suitable in any given case. The author leans very strongly toward steel, and perhaps with reason; but I would not be inclined to accept, as he does, the drift test as indicating where steel could be substituted for iron. A quality of steel that could be subjected in thin sheets to any sort of rough usage without perceptible injury would probably have its strength seriously impaired if treated in the same way, the thickness being increased to the maximum of the rolls. When steel is used in lieu of iron, in addition to the general physical and chemical requirements, the specifications should, in my opinion, contain a clause limiting the maximum thickness of metal.

By Carl Gayler, M. Am. Soc. C. E.

The question of minimum thickness of metal in bridge work is important, and from my own experience I would strongly advocate three-eighths of an inch throughout. Mr. Waddell is willing to stop at five-sixteenths of an inch, except where the metal is very much exposed to the smoke of locomotives, or for horizontal plates that do not drain the water off readily; he therefore concedes that a minimum thickness of three-eighths of an inch is desirable wherever smoke or rust is likely to act on the material. Now in most cases it is impossible to say beforehand which particular portion of a bridge will or will not be exposed to abuse. If we could be sure that the metal work of bridges would receive the proper care, be regularly cleaned, scraped and painted, the case would be different; but the fact is, that after completion of a bridge a careful attention to its proper maintenance, year after year, is the exception, not the rule. There are besides in every bridge some joints which are hard to reach by the painter. Right here might be the proper place to call attention to one feature of our pin-connected bridges in which they are at a disadvantage compared with riveted structures. At every pin joint we have a number of members—bar heads, ends of posts, chord sections, etc.—which are close to each other without being tight together; toc close to allow painting and not sufficiently close to prevent rusting. In some bridges these interstices have been filled with impervious material, but in ninety-nine cases out of a hundred this is not done. The use of packing rings is for this reason also objectionable, as they prevent painting of the pins, without being water-tight enclosures.

As far as the additional cost is concerned, the following argument seems to be very forcible: Any company or corporation or municipality (for I include highway bridges as well) which is able and willing to keep a bridge in good condition is also able and willing to incur the small extra expense implied in the three-eighth inch limit; where, however, the available funds for a new bridge are limited, it becomes doubly important for the engineer to insist on the same, as then it is more than likely that the bridge after completion will not receive the necessary attention. For the above reasons, and taking also into consideration the effect of handling of the material in the shop and during shipping and erection, and the slight increase of the cost, we are justified in insisting on a minimum thickness of metal of three-eighths of an inch in all bridge work.

By Gustav Lindenthal, M. Am. Soc. C. E.

With increasing experience the disagreement among experts on the subject of uniform live loads, vice engine concentrations, will probably disappear. Mr. Waddell makes a timely and effective appeal for a simplification in the computation of stresses in bridges, and I wish to endorse the reasons he gives on this point. In my own practice, if not otherwise obliged, I have for years used an uniform live load expressed by a certain number of pounds per lineal foot, according to the class of bridge required, and in addition a concentrated load rolled over the entire span. For instance, for a heavy railroad bridge, I assume a rolling load of 4,000 pounds per lineal foot, and one additional concentrated load of 40,000 pounds on one axle, and the combination of these stresses would give the maximum strains from live load, including the effect of impact. For lighter structures I use 3,500 and 35,000 pounds respectively, and for the lightest railroad bridges of normal gauge 3,000 and 30,000 pounds respectively. My assumptions give much heavier loads for short spans. This is as it should be. Although we assume static conditions of loading, the swiftly moving loads at the rate of 60 to 80 feet per second cannot be without dynamic effects, which we have at present no means of estimating. They are more severe on short spans, but the above load assumptions give safe and durable structures.

While it is highly desirable in the study of bridge strains to have a clear conception of the action of engine wheel loads, and that the computer be fully disciplined in the calculation of their effects, the practicing bridge engineer may well dispense with time and energy wasting methods, which in no wise furnish safer results in the dimensioning of a bridge. It is one thing to have the mathematical ability to analyze strains with great accuracy if necessary, and another thing to have the good judgment to avoid unnecessary work, when simpler methods give results just as reliable, more easily comprehended, freer from possible mistakes in calculation, easier of checking, and more promising of agreement by different computers in the competition for work. Besides, the assumption of engine concentrations is not even true as representing the actual facts, since the load from the wheels is distributed through stiff rails and through the ties upon the stringers and floor beams in a more or less uncertain manner. The wheel loads, by the time they have reached the stringers and floor beams, are distributed, and are not the single loads assumed to rest on knife edges, and at the same time moving at the rate of possibly 80 feet per second. I agree with Mr. Waddell, that such nice methods, contrasted with the great variations in unit strains, resemble very much the "straining at a gnat and swallowing a camel." When this is better understood by railroad engineers who order bridges, the method of computation by engine concentrations will in practice become obsolete.

WIND PRESSURE.—I should like to add to Mr. Waddell's remarks on this subject, that the lateral bracing of the bridge is more often and more severely strained by the lateral blows from swiftly moving engines and cars, causing lateral vibration, than from the wind itself. Wind force acting on the bridge through an elastic medium cannot be said to cause impact strains, but the lateral bracing is nevertheless subject to the impact strains from railroad trains, causing violent lateral vibration. We have no experiments on the force of such lateral blows from trains, but that they are comparatively severe will not be disputed by any one who has had the experience of standing on a bridge with a fast train rolling over it. In the proportioning of bracing for wind strains, it is probably one of the rarest things to calculate the lateral deflection resulting therefrom. It would show that most bridges of spans over 100 feet would deflect sideways several inches. The difficulty of making proper connections for the lateral bracing in a pin-connected bridge has also not yet been satisfactorily solved. As a general rule, the bracing ought to be made of rigid members, taking compression as well as tension, and thoroughly connecting and riveting up with the stringers and floor beams to add to its rigidity.

Regarding "Group C," namely, "The Styles and Proportions of Bridges," the observations of Mr. Waddell point out the advantages and disadvantages of certain types, although the improvements made in this respect cannot yet be regarded as final. Formerly the bottom chord of framed trusses was made of eyebars from end to end; for short spans these members were very light, and a great many bridges exist of 100-foot spans with six light eyebars in the middle panels of the trusses. After a while the end panels were made of stiffened eyebars or of riveted members, and in several notable instances about one-quarter of the length of the bottom chord at each end was made of rigid members, and there is observable a general tendency to use heavier eyebars, fewer of them and heavier pins. In larger spans this tendency may be carried to a greater extent than is now the practice. It is obvious that it would be better to have two eyebars, 12 x 3 inches, than six eyebars, 8 x 1½ inches. The former would require heavier pins, but would permit of more satisfactory details in the connections, the strains would be concentrated into bulkier and stiffer members, the surface for rusting would be very much reduced. Long vibrating diagonals should be avoided, and in important bridge structures all eyebar diagonals should be stiffened by bracing between them.

The time is fast approaching when buckle-plate floors with stone ballast will be used in place of the present floor system, consisting of oak ties and wooden guard rails. The buckle-plate floor and stone ballast need not weigh more than the oak ties and wooden guard rails. It would add greatly to the lateral rigidity of the bridge, the gravel on top taking the noise out of the structure. The rails could be put in iron troughs to effectually prevent derailment. Re-railing devices and collision piles near the end of the bridge should be added as an effectual protection against failure by derailment.

On the subject of "Intensities of Working Stresses," which is "Group D" of Mr. Waddell's paper, agreement may not easily be reached. Mr. Waddell maintains that mild steel will in the future be used exclusively for all metal railway bridges, because it is practically as cheap as wrought iron, and fully as, or more reliable. In this respect the bridge engineer is dependent on the progress in the metallurgical arts of making wrought iron and steel. The improvements of the last ten years were altogether in the manufacture of steel, and none in that of wrought iron, which is still made by the old laborious and costly process of hand puddling. But the time does not seem to be far distant when wrought iron will be made by some improved metallurgical process in larger masses and at a great deal cheapened cost, and it would not be difficult now to predict whether wrought iron or mild steel in that case would be more largely used. In the use of steel for structural purposes, the preponderance is that made by the Siemens-Martin open hearth process as against the Bessemer made steel. The mild steels will probably always be used for plates and for heavy members made of large single pieces of metal.

Mr. Waddell speaks of fatigue in metal and of the wearing effect of oft-repeated loads. I believe that this theory is based on tests which have no relation to the nature of strains in a bridge. Particularly the theory of fatigue in metal seems to be more romantic than true. If bridges were built to be overstrained, we could with some show of reason speak of physical changes as likely to result from the overstraining of metal. But I cannot see how metal can be fatigued, or in any way affected by strains so far within the elastic limit. There is so far not the slightest evidence for it. With ample allowance for impact in certain bridge members, I believe that uniform unit strains can safely be used throughout for members of ordinary spans and modified, respectively, for tension or for compression. It simplifies the method of dimensioning very much. All compression members in a bridge should be assumed pin bearing at both ends, because in practice the conditions for fixed end bearings cannot be realized with certainty. The formula, for compression, based on the equation of a straight line, is all-sufficient for bridge work, as most practicing engineers will acknowledge.

I firmly believe, that if ever breaking tests were made with full-sized pin-connected trusses, failure would result from the collapse of the compression members long before any tension member would fail. In other words, the factor of safety (to use this convenient if incorrect term) would be found to be less in compression members than in the tension members. This ought to caution us not to go beyond a moderate ratio of $\frac{l}{r}$. It should not exceed 50. It always seemed to me, that in many of the high trestle viaducts, the long slender columns are of meagre safety, although we may show a theoretical justification for so scantily dimensioning these structures. We are taking chances, perhaps not big chances, but still chances, that we do not take with tension members. A slight lateral force from wind, from a flying tree branch, or slight defects in riveting up the composite pieces of a column, may reduce the safety in such a member far beyond what it is calculated for. For this reason I should, as mentioned before, make it a rule to use as low a ratio of $\frac{l}{r}$ as possible. In regard to other unit strains, the designer will find it necessary and proper in longer span bridges, say over 400 feet, to deviate from hard and fast rules of dimensioning and to exercise his best judgment for the sake of economizing metal. The difference between members having to sustain large dead load strains and others with no such strains, or between members with cumulative strains and members subject to sudden strains, cannot be expressed by any arbitrary rule or formula for dimensioning. In larger structures it is necessary to discriminate and to use skilled judgment for that purpose. In this, as well as in the designing of details and connections, the aptitude of the best designers will gradually bring about a certain uniform practice which at present does not exist, although we are approaching it.

By William H. Burr, M. Am. Soc. C. E.

Mr. Waddell's adverse criticism of the use of engine concentrations in the calculation of stresses in bridge trusses is, I think, well grounded. The amount of labor involved in the determination of stresses, with the almost infinite number of different sets of concentrations and wheel spacings which are used in the formation of the diagrams usually prescribed by railroad engineers for the governing of their bridge designs, is certainly most excessive for even the best of computers, except, possibly, now and then one with a most rare mental equipment. Even this requirement of excessive labor might be borne with some patience and equanimity if the resulting computations were entitled to any greater degree of confidence; but as a matter of fact, every engineer knows that locomotive concentrations and wheel spacings for the engines actually constructed upon any one given road will vary from season to season, or even perhaps in the same season; hence if any standard engine or set of standard engines be prescribed with wheel weights to the pound and wheel concentrations to the hundredth of a foot, it is almost a certainty that no locomotive will ever pass over that road and produce the same stresses as that shown with such extraordinary accuracy in the specifications. It is extremely probable that within a short time after the issue of the specifications the load shown will be considerably exceeded, and just why stresses which are absolutely certain to be considerably in error should be computed with such distressing accuracy is not very clear.

Again, if it were among the possibilities that the bridges of any road should carry precisely the locomotives prescribed in the specifications, it is an absolute certainty that the variations in track conditions from one portion of a season to another portion of the same season, under the rapid passage of trains, will produce vastly greater variations from the stresses so accurately demanded than those computed from a simple uniform load or from the latter, headed by a single concentration. Again, the sections of members designed to meet the requirements of a given stress diagram are never mathematically equal to the total stresses divided by the unit stress; nor is it of the slightest consequence that they do so vary; and it is not infrequent that the percentages of such variations are considerably greater than the variations of stresses due to a uniform load from those produced by concentrations. It is therefore most unreasonable and most unscientific that such refined and determined efforts should be made to secure extraordinary accuracy in one direction, only to be completely obliterated and displaced by very considerable but absolutely unavoidable errors or inconsistencies in other directions.

It is to be hoped that the observations of Mr. Waddell will induce engineers to give this matter of bridge loading that thorough and common-sense treatment which it has never yet received, and without which numbers of long-suffering bridge companies' offices have endured untold torments of excessive computation. Nothing is to be gained by this figment of ridiculous refinement; in fact, much is to be gained by its relegation to obscurity. A solacing memory will always be preserved for its admirers by the awe-inspiring literature which Mr. Waddell has pointed out, and which has been written to show what splendid mathematical gymnastics can be performed in its treatment. But it can be confidently asserted that no single structure has ever been made a shade better for its purpose, or more creditable in its design by the use of the method.

I do not concur with Mr. Waddell in his suggestion of displacing this overrefinement by what seems to me to be another almost if not quite as bad If equivalent uniform loads are to be used, then some established position or condition of the engine concentrations must be assumed in reference to the trusses to which they are to be applied, and the load equivalent to them thus placed be found; or else there will be numberless equivalent uniform loads to be determined for each locomotive system. As a matter of fact, there is no such thing as an equivalent uniform load for a given system of locomotive concentrations followed by a uniform train load. Every position of the latter load for every different shear and every different chord stress in a given structure has its corresponding load; that is, such a uniform load as will produce the same shear or the same bending moment as the system of engine concentrations for the position in question. It is true, as Mr. Waddell observes, that such an equivalent uniform load may be found as will make all the truss stresses for a given bridge vary not more than 2 or 3 per cent. from those caused by the concentrated load, but a simple uniform load with a single weight at its head equivalent to the engine excess or excesses will produce a system of stresses with at least the same degree of accuracy, and will thus avoid the tedious computation of an equivalent uniform load.

I see no reason why Mr. Waddell should not go one step further and abolish the equivalent uniform load at the same time that he relegates the engine concentrations to uselessness. The engine or engines which are taken at the head of any prescribed moving load will give a certain excess over an equivalent length of uniform train load. Now, if this excess, considered as a single weight, be placed at the center of gravity of the locomotive or locomotives, the resulting truss stresses will be essentially identical with those caused by the actual prescribed locomotives and train. But if, instead of taking the trouble to find by computation the center of gravity of the locomotive or locomotives, we place this excess as a single weight at the head of the train, we shall make a very slight error only on the side of safety for all the web members, and an equally small error also on the side of safety for the chord members, if we place the uniform load over the whole bridge and then place the single weight in succession at all the panel points of the span. I say place this excess at "all the panel points of the span," for the reason that in all cases the locomotives ought to be preceded and followed by the uniform train load, although this is not often done. If it is not done, an actual condition of loading is ignored, and the resulting error is on the side of danger.

All the computations required for the truss stresses with such a uniform load and a single excess, as is here advocated, involve only the simplest possible stress computations, which can be done with great rapidity by any one who has even a slight knowledge of the rudiments only of the theory. It is rational and scientific, in that the locomotive excess is recognized and provided for in its proper position; at the same time, every possible degree of accuracy which can be attained by any system of computation is also secured. Finally, it avoids entirely the necessity of computing the purely imaginary quantity called the "equivalent uniform load." If there is any valid objection to the uniform load with a single excess found in the manner indicated, I have not yet been able to discover it, and I have never heard it advanced.

In the preceding discussion I have confined myself to truss stresses only, as it seems to me that a system of concentrations should be provided for the design of the stringers and floor beams of a railway bridge. I do not believe it is necessary to prescribe actual locomotive diagrams for such a purpose, although even such a diagram does not involve an unreasonable amount of labor for the purposes of the short plate girders of a railway bridge floor system. I should say that the essential purposes of any system of locomotive concentrations can be secured by a set of weights, three or four in number, as the case may be, which, while arbitrary to a certain extent, can be made easily equivalent to the general type of locomotives in use on any given road. I do not, however, consider this feature of bridge computations a very important one. The calculations involved for a floor system under any system of locomotive concentrations may be considered as too small in amount to merit any very serious discussion. It would simply render complete any simplification for bridge loads by using some such arbitrary system of weights as I have just indicated.

I heartily endorse all that Mr. Waddell states in regard to the use of steel. Whether it will be the material to be used in all bridge spans, both short and long, is simply a question of cost. Whenever a short span steel bridge can be produced at the same or less cost than one of wrought iron, the steel will certainly displace the latter. I am aware that my confidence in the use of steel is not shared by many members of the Society, but I am forced to my convictions by my experience with the metal. I have frequently subjected steel plates and rivets to almost every conceivable manner of abuse by hammering at blue heat and when cold, with the invariable result of increasing my confidence in and respect for the metal. I am now speaking of steel with an ultimate resistance of not over 65,000 pounds per square inch, produced by the open hearth process, and with phosphorus not more than about six or seven hundredths per cent. It is true that I have seen countersunk heads torn off by a very dull flogging chisel under the blows of heavy sledges, but I have also seen the best wrought-iron rivets torn off in the same way with a considerably less number of blows from the same sledges.

The processes for producing structural steel are now so completely under control that it may be produced with the same uniformity as, or greater than, that of wrought iron in the same shapes or bars. The effects that are liable to be produced by the various stages of shop processes, and their influences, are so well understood at the present time that I know of no reason why steel members should suffer under them any more than those of wrought iron; and numberless experiments upon the effect of punching have shown that structural steel of the grade described is less injured than the best of wrought iron used for structural purposes. It is true that cracks must be guarded against, for when once started, if they receive no further attention, their limits are indeterminate; but it is quite true that no process of shearing or punching with tools in anything like respectable condition will start such cracks, and it is not by any means difficult to discover them, even when punching or shearing abuse has brought one into existence.

In the miscellaneous exigencies of railway and machinery practice it has been found that when a metal is demanded that shall possess the longest life under the most severe loading and use wrought iron must be displaced and steel used; and the results of my experience have convinced me that resort may be wisely made to the same material of proper grade in bridge construction. If the so-called mysterious fractures which occur in wrought iron, and in the best grades of that material, were as much talked about and as thoroughly written up as those occasional ones in steel, I have no doubt that general confidence in the latter material would be much less impaired than it is at present. I have known so many failures of wrought-iron members for various purposes which certainly ought to be put in the same category as those so-called "mysterious failures" in steel that I think fibrous wrought iron must be classed as at least as uncertain as homogeneous steel. It matters little whether from the producer or the puddling furnaces to the finished bridge member, steel or iron requires the greater amount of inspection; in either case only the most ordinary and reasonable scrutiny is required.

The subject of permissible working stresses for steel is one which can scarcely be properly covered within the limits of this discussion; but I would say approximately that for the grade of structural steel under consideration the working stresses should not be more than 20 to 25 per cent. in excess of those for wrought iron. The views of wind pressure and resulting stresses taken by Mr. Waddell strike me as being a little too severe. Strictly speaking, we know actually nothing of the quantitative characteristics of wind pressure on large surfaces, but we have every reason to believe that they are much less than ordinarily assumed in bridge specifications. The only possible exception to this statement is that of the pressure of the most intense cyclones; and even in such cases the highest pressures probably do not cover more than a portion of the surface enclosed in the outline of a truss 500 feet in length.

I think the suggestion to stiffen the two lower chord end panels at each end of a span is one that should be followed; but I do not believe it is correct to consider the end post in the computation of portal stresses as resting upon a pin at its lower end. It may not be, and probably is not, strictly a flat end column, but it is quite certain that it is not a pin end column. I believe it to be much nearer the former than the latter, and would so consider it in all cases, as being a sufficiently close approximation. I believe also that so long as the wind stresses in the lower chords of bridges do not exceed three-eighths of those caused by the fixed and moving load, they may be neglected. In computing these stresses, however, for the reasons already given, it does not seem to me essential to consider the transferred truss and moving loads, either for the stringers or the lower chords. The ordinary method of designing stringers and floor beams gives a sufficient margin of safety over and above the nominal working stresses to provide for any excess due to transferred loads from wind pressures; and although the method is not strictly scientific, it involves no appreciable waste of metal, is sufficiently near for practical purposes and avoids useless refinement and complication. Regarding the wind loads in the upper chords or trusses, I can see no improvement over considering them carried by the upper lateral bracing directly to the portals, and through the portal posts to the wall plates.

By L. L. Buck, M. Am. Soc. C. E.

The title of Mr. Waddell's paper is somewhat of a misnomer, inasmuch as many of the points considered are not disputed. I intend, only in discussion, to briefly state my own opinion regarding a few of those points upon which I do not agree with him. The question of using equivalent live loads, considered as uniformly distributed, might, in some cases, simplify computations; and might not be objectionable if we were sure that the computation of stresses would always be performed by competent men, who would carefully watch all changes in distribution of live loads and estimate the proper uniform equivalents. But much of the success which has attended American bridge engineering has been due to men who were willing to devote the labor necessary to following through, in detail, the stresses produced by the various distributions of the live loads; and it will be an unfortunate condition which shall drive such men from this work until we have arrived at more permanence in the various classes of loads, and construction has reached a point at which further improvement is not needed. That point is not yet in sight, and more hard work will be necessary before we reach it. When Mr. Waddell comes to the subject of "wind pressure," he appears to have adopted a more complex treatment. Here we are dealing with a force whose effect upon surfaces of large extent we have no means of accurately gauging, and it is difficult to see how a suitable gauge can be constructed. But it is safe to assume that rules regarding it which have proved safe during the years that they have been in use will continue to be so in the future.

As to the styles and proportions of bridges, there are several forms of truss which have given good results. The riveted lattice can be made very efficient, and in its construction there appears to be no objection to multiple triangulation. The Pratt truss, with vertical intermediate and inclined end posts, has undoubtedly met with the greatest favor for railroad bridges.

It gives reasonable simplicity of construction and promptness of erection. In arranging the trusses my preference is for single triangulation, and, within reasonable limits, to use as long panels as the length and depth of span and proper inclination of the diagonals will allow. In this connection it does not appear clear why Mr. Waddell proposes to increase the width of the body of the lower chord eyebar, as he increases the length of the panel. As the span is increased it is necessary to use larger bars to avoid too great length, in proportion to diameter, of pin. But there is no economy in attempting to make the bar act as a beam in sustaining its own weight. The nearer it can come to assuming the catenary due to its own weight and the tensile stress upon it, without acting as a beam, the better. Stiff lateral diagonals doubtless give greater lateral rigidity to the track floor, and if secured to the lower flanges of the track stringers where they intersect them, are economical. It is desirable, as far as possible, to have the lines of the diagonals pass through the intersections of the axes of posts and chords. But it is difficult to accomplish this where eyebar chords are used—practically, it is apparently impossible. Stiff or riveted-up chords lend themselves to this purpose more readily, and in spans up to 175 feet, where often the end panel and that next to it are made stiff, it might be well to consider the advisability of making the chord stiff throughout.

The suspending of the floor beams of iron truss bridges under the lower chord is objectionable generally, though in the case of drawbridges it has the advantage of allowing the lower chords to have nearly as great exposure to the direct rays of the sun as the upper, and thus, in a measure, preventing the diurnal fluctuations of the elevations of the ends. The spaces between center lines of iron or steel track stringers is important. If too near together, they are not only dangerous in case of derailment, but the rolling tendency of the locomotive when laboring, and of the cars from wind pressure, subjects them to a greater stress than is often taken into account. My own practice is to place them 7 feet apart. Regarding their fastening to the beams, I have never known any to get loose when secured to the beam webs in the usual manner with a sufficient number of rivets. If the stringers have a sufficient depth, the curvature of their deflection will not exceed that of the span sufficiently to produce any serious stress upon the connecting angles.

In re-enforcing the upper flanges of transverse beams, where the tops of the stringers are below the tops of the beams, I have sometimes used a piece of channel with trough side up, and its web riveted to the beam flange, instead of a cover plate, and laid a piece of timber in the trough, with its upper surface level with that of the cross-ties. This gives less thickness to rivet through, gives greater lateral stiffness to the flange, and permits of leaving a space between the beam and the nearest cross-tie on each side.

The intensity of unit stresses is an important one. It would be still more so if we had arrived at a maximum intensity of live load, but at present a small unit stress for the live load appears desirable, for the reason that we may reasonably anticipate that increasing intensity of the live loading will make its unit stress large enough in the near future; and if we can deceive ourselves into the belief that a very small unit stress for the live load in proportion to that for the dead load is necessary, our bridges will last the longer for it.

All these questions are so interesting, and so many of us have learned to look forward to continued growth in knowledge regarding them, that we cannot avoid hoping that their final settlement for all time may not be so near as the final clause of Mr. Waddell's paper appears to indicate.

By J. B. Johnson, M. Am. Soc. C. E.

It would seem that Mr. Waddell has made out a satisfactory case against the further use of wheel load systems in the designing of simple railway truss bridges. Although the technical schools have not in any way been responsible for the introduction of these laborious methods, they have tried faithfully to adapt the instruction in this branch of engineering to the requirements of actual shop practice, and are therefore largely responsible for the great elaboration of many of the details and graphical expedients which now are recognized as essential features of them. The professors in these schools will, however, welcome a return to shorter and simpler processes if they can be shown to give satisfactory results. The two years which our engineering schools can give to imparting strictly professional instruction should be reserved, as far as possible, for the teaching of principles, and as little time given to methods as is consistent with a fair degree of efficiency in field and office on graduation.

An entire abandonment of the concentrated wheel loads processes would result in a considerable saving of time, which might be more profitably spent in the further study of principles. It has been the writer's custom to prove theoretically to his classes that if a uniform loading be taken, giving the same bending moment as the wheel loads at the "quarter point," or at the joint nearest to this point, the resulting stresses in all members will very closely approximate to those from the actual wheel loads moved across the bridge. Mr. Waddell's table on page 270 is a further proof of this fact. Omitting his 100-foot truss span, of four panel lengths, as being too short for such a comparison of methods, but taking his other lengths up to 300 feet, we have:

Load.	150-foot Span.	200-foot Span.	250-foot Span.	300-foot Span.
Mr. Waddell's average unit load....................	3215	3151	3112	3085
Unit load at quarter point..........................	3214	3120	3107	3094
Percentage of difference..............................	0.0 per cent.	1.0 per cent.	0.2 per cent.	0.3 per cent.

It would appear, therefore, that the "quarter point" might well be taken as the point at which to compute an equivalent uniform load, giving the same bending moment as the maximum moment from concentrated or wheel loads. The equivalent uniform load per foot for this position is

$$w = \frac{32\ M}{3\ l^2} \dots\dots\dots\dots\dots\dots\dots (1)$$

where m = maximum moment at the exact quarter point for wheel loads. This equation to be used where the number of panels is a multiple of four.

If the quarter point does not fall at a panel point, or when the number of panels is not a multiple of four, then take the nearest panel point, preferably that one towards the center from the quarter point, and use the following equation:

$$w = \frac{2}{m\,(n-m)} \cdot \frac{M_m}{p^2} \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

where w = equivalent uniform load per foot.

n = number of panels in bridge.

m = the number of the panel point taken, counting from the near end and calling the end support zero.

M_m = maximum moment at the mth joint for the concentrated wheel loads.

p = panel length in feet.

Equation (2) reduces to the form given in (1) when n is a multiple of four.

FLOOR BEAM CONCENTRATIONS.—Mr. Waddell seems to have never read Professor Swain's paper on "Stresses in Bridges" in the Transactions Am. Soc. C. E., Vol. XVII, where, on page 37, the method of finding floor beam concentrations from the equivalent uniform loads, rediscovered by Mr. Waddell, is fully explained.

FIBER STRESS IN EYEBARS FROM THEIR OWN WEIGHT.—Mr. Waddell, in common with many other bridge engineers, opposes the use of long shallow bars because of the unknown fiber stresses caused by the dead weight of the bar. This is an interesting question, and so far as the writer is aware it has not been investigated. When an eyebar is pulled to its working limit, it is still bent downwards by the full force of gravity upon it. But when it sags from a straight line, the pull on the bar, as well as the bending stresses, tend to hold it straight. There are, therefore, two external forces acting on the bar, one tending to deflect it and the other tending to hold it straight. The residual bending moment is held in equilibrium by the resulting moment of resistance in the bar.

If a section be taken at the center of the bar, we have—

$$\frac{Wl^2}{8} - P\,v = \frac{fbh^2}{6} \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

where w = weight of bar per inch.

l = length in inches.

P = total pull on bar.

v = deflection of bar at center.

f = fiber stress due to this deflection.

b = breadth of bar.

h = height of bar.

But $w = 28\,bh$.

$P = pbh$, where p = working tensile stress on eyebar.

$v = \frac{5}{24}\,\frac{fl^2}{Eh}$ where E = modulus of elasticity = 28,000,000; whence we have—

$$f = \frac{4{,}700{,}000\ h}{p + 22{,}400{,}000\left(\frac{h}{l}\right)^2} \ldots\ldots\ldots\ldots\ldots\ldots (4)$$

If, in this equation, the first differential co-efficient of f with respect to h be put equal to zero, we obtain, for the depth of bar giving maximum fiber stresses—

$$h = \frac{1}{4,730} \sqrt{p} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (5)$$

If this value of h be substituted in Equation (4) we have, for the maximum fiber stresses for those depths given in Equation (5)—

$$f\ \text{max.} = \frac{500\ 1}{\sqrt{p}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (6)$$

From Equations (5) and (6) the following table of depths giving maximum fiber stresses, and the corresponding stresses per square inch on the extreme fiber, due to bending only, has been computed:

TABLE OF DEPTHS AND MAXIMUM FIBER STRESSES.

Working Tensile Stresses in pounds per square inch	LENGTH OF EYEBARS IN FEET.											
	15		20		25		30		35		40	
	Depth	Fiber Stress	Depth	Fiber Stress	Depth	Fiber Stress	Depth	Fiber Stress	Depth	Fiber Stress	Depth	Fiber Stress
	In.	Lbs., Sq. Ins.	In.	Lbs., Sq. Ins.	In.	Lbs., Sq. Ins.	In.	Lbs., Sq. Ins.	In.	Lbs., Sq. Ins.	In.	Lbs., Sq. Ins.
8 000	3.4	1 010	4.5	1 340	5.7	1 680	6.8	2 020	8.0	2 350	9.1	2 690
10 000	3.8	900	5.1	1 200	6.3	1 500	7.6	1 800	8.9	2 100	10.1	2 400
12 000	4.2	820	5.6	1 100	6.7	1 370	8.4	1 640	9.7	1 920	11.1	2 190
14 000	4.5	760	6.0	1 020	7.5	1 270	9.0	1 520	10.5	1 780	12.0	2 030
16 000	4.8	720	6.4	960	8.0	1 200	9.6	1 440	11.3	1 680	12.9	1 920

For other depths, lengths, or tensile stresses, use Equation (4).

From this table it is evident that the depths producing maximum bending fiber stresses are in general those in common use. Also that the bending stresses in the extreme lower fibers, which are to be added to the working stresses, are not inconsiderable, but will vary between 10 and 20 per cent. of the working stresses in lengths of from 15 to 30 feet.

By Henry T. Eddy, C. E.

This paper is a move in the right direction. If an agreement can be secured among bridge experts as to the various points noticed in this paper, it will, I am sure, mark a distinct advance in bridge designing. I am especially interested in that part of the paper which relates to computation and to the adoption of some limited list of typical loads. An agreement as to the amount and distribution of the wheel concentrations which bridges shall be designed to carry is wanted by those who advocate the employment of equivalent uniform loads, as much if not more than by those who propose to compute directly from the wheel loads themselves; for the only basis for these equivalent loads is the amount and distribution of wheel concentrations in place of which they are taken.

It seems to me that Mr. Waddell's reference to my paper is based upon a misconception which I desire to remove, and at the same time assist, if possible, in deciding the question whether computations may be best based upon assumed wheel concentrations or upon so-called equivalent uniform loads. The sole advantage of employing uniform loads is found, I take it, in the ease and simplicity of computation. The disadvantages are, that the equivalent load is only approximately equivalent, and owing to the way it is found, the degree of approximation and amount of the error are unknown and, in fact, vary from point to point of the span. Furthermore, the magnitude of the equivalent load varies for a given train with the length of the span. The general opinion at present is, that the principal members of long span bridges can be computed satisfactorily from equivalent uniform loads; but in short spans and in stringers and other details of long spans, where the wheel concentrations exert a more preponderating influence, I am led to believe that it will still continue to be required that the designer and computer shall take account of the wheel concentrations, however much he may dislike the work, or however certain he may be in his own mind that it involves unnecessary labor.

It was in view of a probable continued use of concentrated loads that I attempted* to explain graphical methods of treating such loads, methods which I think I am justified in saying are as simple and as expeditious as that of equivalent uniform loads, but which involve no approximation whatever. If I have succeeded in doing this, then the whole burden of objection urged against employing concentrated loads vanishes. As I understand it, computers would gladly use concentrated loads in case the labor were no greater than in using uniform loads. Now I distinctly claim that the methods proposed in my paper enable the computer to do this, and I have only to refer in corroboration to those who have tried both methods. Notice, however, that I do not claim at all that the algebraic proofs which I have given of these methods are in any sense simple or expeditious. In all candor I must acknowledge that I could wish these were less tedious, and I am sorry that I have been unable to discover less intricate demonstrations of these simple and convenient processes. I am well aware that such demonstrations are likely to stand in the way of the ready diffusion of a knowledge of the methods proposed, for no engineer will be willing to adopt methods of whose truth he is not satisfied. I trust that more simple demonstrations will in time be found, or that the ability to read mathematics will become so general as to do away with this obstacle.

The misconception into which I think Mr. Waddell has fallen respecting my paper is in supposing that the formulas I have used were intended for computation. Such is not the case; they are simply used, most of them, to convince the reader once for all of the correctness of the process he is directed to use, otherwise they might have been omitted. There are, however, certain side developments in my paper, intended specially for those who wish to compute by the method of equivalent uniform loads. The developments I refer to are simple approximate formulas for finding equivalent uniform loads and the approximate maximum shears at the head of a train. These formulas derived on mathematical principles permit us for the first time, so far as I am aware, to do the very things which Mr. Waddell desires to

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* Transactions Am. Soc. C. E., May, 1890.

do, and to do it in some other way than by "cut and try." It may become possible to gain some idea how closely the results of such a formula approximate to those obtained from the concentrations themselves.

By Edwin Thacher, M. Am. Soc. C. E.

A.—I fully agree with the author, that the substitution of equivalent uniform loads for wheel concentrations in bridge calculations is a great saving of labor, and also that the results are practically as accurate. I have calculated stresses both ways, for hundreds of bridges with all the aids to calculation that are available, and I should judge that the time required for the calculation of stresses, using uniform loads, does not exceed one-tenth the time required if wheel loads are used; in fact, with a good slide rule the stresses can be found, using uniform loads, while one is getting ready to make a start with wheel loads. It may be asked, if the results are practically as accurate by uniform loads, why not always use them? One reason for not doing so is that an engineer naturally has a pride in having his strain sheet conform strictly to specifications; but another and the principal reason is that wheel loads give somewhat less material in the chords and counters, and under close competition economy is necessary. For spans up to 150 feet the difference is not very important, but for long spans it is quite considerable. If the train load precedes as well as follows the engines, however, which is not uncommon, the stresses by uniform and wheel loads for spans of any length, including cantilevers, give results almost identical.

As I have already in previous discussions given my views quite fully on the question of uniform vs. wheel loads (see "Specifications for Strength of Iron Bridges," by Joseph M. Wilson, M. Am. Soc. C. E., 1886, and "Stresses in Railway Bridges on Curves," by Ward Baldwin, M. Am. Soc. C. E., 1891), I do not wish to make any repetitions here. In finding the stresses by wheel loads or in making a table of equivalent uniform loads, the first thing to do is to prepare a moment table, viz., a table giving the moment about each wheel of all preceding wheels. With such moment table at hand, it is a matter of only two or three minutes to find the maximum end shear on a stringer or plate girder, and I have never felt any great need for a table to cover this case. It would be well, however, when preparing tables of uniform loads corresponding to maximum moments, to make one also corresponding to maximum shears, and thus dispense with moment tables altogether. The method given by the author for finding the concentrated load on floor beams and suspenders by using the equivalent load corresponding to a length of two panels, is not new. It has been used extensively by me for eight or ten years. An example of such application may be found in my paper, Transactions Am. Soc. C. E., May, 1884.

The author appears to have based his equivalent loads for all spans upon the maximum bending moment. I do not think it advisable to do this for spans exceeding 90 to 100 feet in length, or for spans greater than the longest plate girder used. A latticed girder I would never use unless forced to do so, and for trussed spans I consider it preferable to base the equivalent load on the maximum shear, in which case the stress in end brace and end chord by uniform load and by wheel loads will be identical, the stresses at center of chords and in counters being slightly in excess by uniform loads. The results will vary somewhat with the number of panels used, so that in preparing a table for spans of 100 feet and upwards it would be advisable to give a choice in a number of panels.

In the general specifications of the Keystone Bridge Company are given diagrams and equivalent uniform loads for ten different classes of engines. For spans up to 70 feet, the loads correspond to maximum moments; and for spans of 75 feet and upwards, to maximum shears. Since this table was prepared (1887), some of these loads have dropped out of specifications, and others have come in, and the table could be profitably revised accordingly; but a choice of ten different and well-selected classes of loading, it appears to me, ought to satisfy any railway company. I consider that the calculation of stresses by uniform load is really better practice than by wheel load; for it not only saves nine-tenths of the time in calculation, but is always safe, and provides, as before noted, for a possible condition of loading not usually provided for when wheel loads are used. When required to make a large number of estimates in a very limited time, as all bridge calculators frequently are, I always use uniform loads, let the specifications be what they may, as it becomes simply a matter of choice to do this or not to bid on the work. There is no question, in my mind, but what uniform loads could be adopted in railway bridge specifications with great profit to the bridge companies and without injury to the railway companies.

I do not think the typical live loads proposed by the author the best selection that could be made. I would prefer to take the actual engines and loads in use and specified by railroad companies as far as possible, say the following selections:

1.—Erie. 2-80.75 ton consolidation engines followed by 2,240 pounds per lineal. foot.

2.—B. & O. 2-86.0 ton consolidation engines followed by 3,000 pounds per lineal foot.

3.—P. C. & St. L. 2-92.3 ton consolidation engines followed by 3,000 pounds per lineal foot.

4.—L. & N. 2-97.75 ton consolidation engines followed by 3,500 pounds per lineal foot.

5.—Penn. 2-100.0 ton consolidation engines followed by 4,000 pounds per lineal foot.

6.—E. T. V. & G. 2-105.0 ton consolidation engines followed by 4,000 pounds per lineal foot.

7.—R. & D.—2-112.0 ton consolidation decapod engines followed by 4,000 pounds per lineal foot.

8.—Lehigh. 2-126.0 ton consolidation engines followed by 4,000 pounds per lineal foot.

9.—L. & N. 1-80.5 ton, 8-wheel engine, 68,000 pounds on drivers, 9 feet centers.

10.—Penn. 1-89.0 ton, 8-wheel engine, 80,000 pounds on drivers, 8 feet centers.

Loads 9-10 apply only to cross-ties and short spans.

Railroad companies are not likely to change their specified loads unless they find it to their interest and advantage to do so; neither do they care how much work and expense is borne by a bridge company in estimating on their work, so long as they do not have the bill to pay. For these reasons I do not think it probable that the author's proposed loads will be adopted to any great extent, and if not adopted the tables prepared therefrom would be useless. On the other hand, tables of equivalent uniform loads, corresponding to the engine and train loads above given, would be very useful to all calculators and a valuable contribution to bridge builders, independent of any action that may be taken by the railroad companies; for they could be safely and profitably adopted by the calculators in all cases for spans up to 150 feet; and if railroad companies would provide (as does Mr. Bouscaren in his specifications) for a train load to precede as well as to follow the engines, they would get a better bridge, and calculators would be relieved of a great burden, as uniform loads can then be adopted in calculation for spans of any length. Railroad companies can then continue to specify wheel loads if they prefer to do so, and all parties will be satisfied.

B.—For wind pressure, I believe an allowance of 150 pounds per lineal foot for unloaded chords, and 450 pounds per lineal foot for loaded chords for spans up to 200 feet, is ample for ordinary cases. For longer spans greater allowance should be made, and for special cases of double decks, high fences, etc., 30 pounds per square foot of exposed surface appear to me sufficient. To resist these forces, I would allow 20,000 pounds per square inch on iron lateral rods. It is not likely that one bridge in ten thousand is ever exposed to a wind force of 30 pounds per square foot, or one bridge in a thousand to a force of 10 pounds per square foot. Even if it should be exposed to a force greater than 30 pounds, the bottom chords of the great majority of trussed bridges would be buckled before the stress in the rods reached the elastic limit. My ideas on the wind question are given quite fully in discussions of Paper No. 335, Volume XV, wherein is given an example of a 200-foot span through bridge. In this example, the trusses are 17 feet 9 inches center to center, better designed than the average through bridge and far better than the average deck bridge to resist wind; yet it is found that a force of 20 pounds per square foot will buckle the second panel of the bottom chord; a force of 23 pounds, the third panel; a force of 31 pounds, the fourth panel; a force of 35 pounds, the fifth panel; and a force of 39 pounds, the center panel.

Specifications frequently make excessive provision for wind and initial stress, which, if observed, leads to much waste of material. Mr. Cooper, who is entitled to much credit for originality, and whose specifications bear evidence of careful study, makes a very wild provision for the force of wind on iron trestles, and if any trestle has ever been built to conform therewith, I would be glad to make a note of it. Applied to a recent estimate for a trestle 60 feet high, with alternate 30 and 37.5 feet spans, the bents should have a width at base of about 109 feet to prevent tension; or, allowing the usual batter of one horizontal to six vertical, the tension will be sufficient to lift 280 cubic feet of masonry—an absurd result in either case.

C.—I would leave the style of bridge to the designer, as nearly any style can be made to do its work well. Plate girders much exceeding 90 feet in length are troublesome in most shops and liable to injury in transportation and erection. Pony truss railroad bridges are not called for of late years to my knowledge, and many of the old ones have fallen down. They may be considered structures of the past. I prefer to have floor beams riveted to vertical posts in through bridges, provided the rivets are in double shear; but floor beams suspended by plate hangers admit of good details and a quite rigid lateral system. I do not see the force of the author's remarks that, in the subdivided Pratt truss, rigidity is increased and the top chord sections are more perfectly supported by sub-strut than by sub-tie. I prefer the tie for appearance sake, though in all comparisons made the strut is least expensive, as stress travels in a much more direct route to the supports.

If the width between centers of trusses in long span bridges is one-twentieth of the span, the span becomes practically a trussed column of 20 diameters, and the top chord sections (whatever their dimensions) should not be proportioned for a less number of diameters. This consideration alone is sufficient to govern the width between trusses after obtaining the necessary clearances. No doubt an increase of minimum clear width from 14 to 16 feet would make a safer bridge, but it rests with the railroad companies to decide whether the extra safety is worth the extra cost. I prefer a space of 9 feet between centers of track stringers. This allows guard rail, cross-tie, and stringer to be connected conveniently by the same bolt; it is cheaper than any less width, and less effect or inequality of stress is produced by train oscillation. It requires a heavy timber floor, which is an advantage and materially assists the bottom chord to resist reverse stress from wind, and we have found this needed if only 30 pounds per square foot pressure is specified.

D.—I doubt whether steel will ever be used in bridge work more extensively than it now is. There is no economy in reamed steel for small trussed spans. Steel of the mildest grades is less reliable than iron. In the dropping or overturning of girders in wrecks, careless handling, or abuse of any kind, steel suffers much more severely than iron. Steel is unquestionably safe under ordinary conditions of stress, but I do not believe it can ever be made the equal of iron under all conditions.

As remarked by the author, the intensities of working stresses that should be used on bridge material remains much a matter of individual judgment on the part of the engineer. The author appears to have adopted for tension members the fatigue formula recommended by Launhardt, instead of a modification providing for impact, and asserts that a formula involving the factor $\left(1 + \frac{\text{maximum}}{\text{minimum}}\right)$ is surely incorrect. I do not agree with him. Whether bridge material does or does not suffer fatigue is a matter of no great consequence. All engineers are agreed, that greater provision should be made for a live load than for a dead load, and my own opinion is that about double provision should be made; as, for example, I consider a member subjected to a constant stress of 15,000 pounds per square inch as safe as a counter rod in a bridge figured for 7,500 pounds per square inch. Having fixed on the minimum and maximum limits of stress, it appears to me reasonable to draw a straight line between them, and let all intermediate values of $\frac{\text{min.}}{\text{max.}}$ be found on this line; the formula does this and nothing more.

If an engineer considers that members subject to dead loads should be allowed only 25 per cent. greater stress than for live load, he can use the formula $a\left(1+\frac{\text{min.}}{4\text{ max.}}\right)$.

If he wishes to allow 50 per cent. greater stress for dead than for live load, then he can use $a\left(1+\frac{\text{min.}}{2\text{ max.}}\right)$.

If 100 per cent. appears correct, he can use $a\left(1+\frac{\text{min.}}{\text{max.}}\right)$, as I make a practice of doing.

These formulas recognize fatigue only to a small extent. The formula $7{,}500\left(1+\frac{\text{min.}}{\text{max.}}\right)$ for iron tension members appears to me good enough. Mr. Cooper allows 8,000 pounds for all live load and 16,000 pounds for all dead load, which gives a variation from the formula of 6 per cent. at extreme limits and less than this at all other points. The application of Mr. Cooper's specifications in their present form is burdensome to computers. owing to the necessity of finding the stress for dead and live load separately for each individual member. This may be avoided, using only maximum stresses, and the same results be obtained by stating the requirements as follows:

Eyebars......... $P = 16{,}000 \div \left(1+\frac{\text{live load}}{\text{max. load}}\right)$

Plates and shapes. $P = 15{,}000 \div \left(1+\frac{\text{live load}}{\text{max. load}}\right)$

Chord segments... $P = (16{,}000 - 60\frac{1}{r}) \div \left(1+\frac{\text{live load}}{\text{max. load}}\right)$

All posts.......... $P = (14{,}000 - 80\frac{1}{r}) \div \left(1+\frac{\text{live load}}{\text{max. load}}\right)$

The above modification will be found to save considerable labor. The ratio of $\frac{\text{live load}}{\text{max. load}}$ for web members may be taken from the shears; and for chords from the assumed dead and live load per lineal foot. If the views of S. W. Robinson, M. Am. Soc. C. E., in regard to the effects of cumulative vibrations be accepted as facts, all of our specification will need material revision. The example given by the author of two long duplicate suspension bridges does not sustain his point. The formula which will allow a stress of 40,000 pounds per square inch in the first case is $20{,}000\left(1+\frac{\text{min.}}{\text{max.}}\right)$, which for the second case allows 33,333 pounds per square inch, or practically, if 15,000 pounds is allowed in the first case, 12,500 pounds will be allowed in the second, which appears to me about right. As the second case requires but nine-tenths as much material as the first, it is of course the stronger under the assumed condition of loading. In discussion of Paper 335, Vol. XV, previously mentioned, I proposed the following formula for the ultimate strength of iron columns:

Flat ends $P = 45{,}000 - 150\frac{1}{r}$, Pin ends $P = 45{,}000 - 200\frac{1}{r}$.

these formulas representing nearly mean results of all experiments recorded and plotted up to that time. I do not think there have been a sufficient number of tests made of the compressive strength of steel bridge members upon which to base formulas, but if we assume that for short blocks the strength is in proportion to the tensile strength of the material, and agree with Mr. James Christie, M. Am. Soc. C. E., that mild or medium steel has the same strength as iron when $\frac{l}{r} = 200$, we readily derive the following formulas for steel columns:

Ultimate strength, 60,000 to 68,000 pounds per square inch or 64,000 pounds per square inch mean:

Flat ends $P = 57{,}500 - 215 \frac{l}{r}$, Pin ends $P = 57{,}500 - 260 \frac{l}{r}$.

Ultimate strength, 68,000 to 75,000 pounds per square inch or 72,000 pounds per square inch mean:

Flat ends $P = 65{,}000 - 250 \frac{l}{r}$, Pin ends $P = 65{,}000 - 300 \frac{l}{r}$.

The above formulas both for iron and steel err on the side of safety for very long columns, but as the effect of the weight of the column itself is not always considered in calculation this is desirable.

E.—I do not consider it necessary to add to the section of bridge members on account of wind stresses unless they exceed the amount due to dead and live loads; for not only is the bridge very unlikely ever to be subject to anything approaching the wind assumed, but should this happen the stress would still be well within the elastic limit, and safe. I have made a practice of adding to the sections of trestle legs when the combined stress exceeded by 50 per cent. that due to dead and live loads only, but believe that 100 per cent. would be better in this case, as there is no merit in wasting good bridge material. In my paper, Vol. XIII, Plate I, Transactions Am. Soc. C. E., are given the stresses in three varieties of bridge portals. I investigated the subject at that time and have used the results since. They are correct according to my views, and as I have not seen them in print elsewhere they may be of some service to bridge designers.

F.—I do not agree with the author that plate girder proportioning amounts to but little more than rule-of-thumb. To be sure, some peculiar and untenable theory is occasionally advanced, but in all important particulars I believe the stresses in plate girders are as well known, and admit of as clear demonstration, as in other structures.

G.—I would never use unreamed compression steel of any grade under any circumstances. It may stand the drift test and bend double upon itself, yet, in the careless upsetting of a girder, crack like glass. As regards the use of steel, the question as to the most desirable grade to use has more interest to me than any other; if very mild steel is used in compression, the cost of reaming prevents in a great measure its economic use as compared with iron, and unless some very decided saving can be effected by its use I would much prefer iron. I have favored, both for tension and compression, a steel having a mean ultimate strength of about 70,000 pounds, although I believe a majority of engineers favor a lower grade. I am in favor of the grade mentioned for several reasons; its use effects a material saving in the cost of structures; it can be furnished of uniform quality; its elastic limit and reduction of area are superior to iron, and in cold bending

it is nearly or quite the equal of iron, and when annealed after forging and when reamed after punching, it appears to me to be as safe as the milder grades. If this is true, why throw away a strength of 10,000 pounds per square inch? and if not true, I would be glad to hear some good and substantial reasons why. I would be glad to hear an expression of opinion on this important question of economy.

By C. L. Gates, M. Am. Soc. C. E.

In the discussion on the valuable paper entitled "On Specifications and Strength of Iron Bridges," read by J. M. Wilson, M. A. S. C. E., in Transactions, Vol. XV, 1886, the fact was forcibly brought before the Society by several of our more prominent and well-known bridge engineers, that in preparing strain sheets for bridge trusses a great amount of practically useless labor was imposed upon the contracting engineer to provide for the maximum strain caused by any one of the various engine wheel loads specified; and I am glad that Mr. Waddell at this time has again taken the initiative to bring this matter before the Society. Ever since the matter of engine concentration from wheel loads was considered in connection with iron bridge building, it looks as though it had been the ambition of railway engineers in writing up a bridge specification to adopt an actual or typical engine load differing in wheel base and load from previously accepted ones, and yet in its resulting strains varying but slightly from the engine load of the rival railroad. Yet this slight variation requires an amount of labor not appreciated and hardly compensating for the accuracy in result, all of which Mr. Waddell clearly points out and proposes to remedy in substituting arbitrary formulas closely approaching correct results.

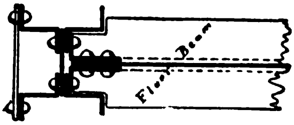
To me it seems we might at this time agree upon three or four typical engines or equivalent concentrated loads covering nearly all cases of loadings, and I should be pleased did Mr. Cooper so modify his standard wheel load to approach those of Mr. Waddell's proposition, Mr. Cooper's specifications having already so wide a reputation and having been adopted extensively by railroad engineers as a standard. Very likely the gentleman has already anticipated this necessity. I have for the past six or seven years slightly modified such wheel distances and loads for personal convenience in computation without varying from the general result except on the safe side.

Similar conditions of things at present exist in the various compression formulas. Without further touching upon the great divergency of established rules, I simply mention that Cooper's formulas for steel compression members in long length columns give smaller resulting unit strains than for precisely equivalent iron sections, and to this time I have never been able to fully explain the very small unit strain allowed for long posts compared with the large unit strains permitted for end chord sections by the above-mentioned author.

With regard to requirements of stiffeners in plate girders it has been my habit to formulate for distances between stiffeners, also for the required area of the same and the number of rivets per stiffener, providing for the intensity of shear at the point in question compared with the ratio between the web depth and web thickness and total net web area, disregarding the

usual clause in specifications to space stiffeners at distances equal to the depth of girders and never less than 5 feet apart. I believe, however, that not much is gained by hair-splitting differences in discussion, if we at the same time in designing and building diverge widely from good accepted practice and standard. I am surprised to find at this date in one of our large cities a long three and four track railway viaduct in process of construction, consisting of 30 feet, 40 feet and longer deck-plate girder spans designed for very heavy traffic and engine load, in which vertical web stiffeners for $4\frac{1}{2}$ foot depths have been placed at the certainly extraordinary distance of 15 feet from the end stiffeners. If this viaduct is being built in accordance with modern practice I should like to know it, and have the engineer and designer, a member of our Society, to inform us; and if it is not, discussion on the subject would be beneficial and perhaps remedy such incongruity in details in an otherwise careful and skilful design.

Another point I wish to bring up is this: Why are hip joints at intermediate panel points (between the inclined and horizontal top chord sections) in some of our most important long span structures designed as though the transferred strain were through the "inclined" bearing surfaces instead of through the medium of properly proportioned riveted reinforcement plates and the pin such as we all very properly design for the end hip joint? With reference to general details of construction, it has been the writer's favorite custom to connect four beams to Z (zee) iron posts as per sketch; this connection having the advantage that the beam is attached to the post through its neutral axis, doing away with the diaphragm plate ordinarily used for the purpose of equalizing the load over the two channels of the post. In conclusion, I would suggest that when Mr. Waddell establishes a formula for unit strain in steel under compression he should at the same time specify the grade of steel proposed to be used, a matter of the utmost importance.



By Charles S. Churchill, M. Am. Soc. C. E.

I am much interested in the paper under discussion for the following reasons:

FIRST.—There is certainly entirely too much variation in the specifications of live loads for new bridges.

SECOND.—There are no good grounds for this great variation.

THIRD.—I think that the present varied practice will soon be simplified by the suggested discussion.

FOURTH.—This subject has been one of very great interest to me and to all the members of the Engineering Department of the Norfolk and Western Railroad for over three years.

In 1888 it was found necessary to make some very radical changes in our bridge specifications, principally on account of the adoption of heavier engines and cars, and, further, from the discovery that we had ahead of us an extremely large amount of bridge work. At the outset it was found that we could not adopt any special type of engine for a maximum live load, because many changes were probable, and, indeed, were made, before any specifications were completed. It was also thought that the weights of our engines might be further increased in a few years. It was determined, therefore, to adopt the simplest plan of typical loading we could devise, that would secure to us bridges having a proper per cent. of excess strength; and to arrange that loading so that a change in the wheel base of any of our engines or the weight on any wheel would not destroy the adopted per cent. of excess strength of our bridges. The problem was very soon found to be a very difficult one and months were spent upon it.

The attempt was made at first to use a single concentrated head load, followed by a uniformly distributed train load. This plan, when adjusted to give the proper excess strength to bridge members governed by the maximum bending moments, would give entirely too small an excess to the strength of members governed by the maximum shearing forces. The conclusion was reached, therefore, that the proper plan of loading is a series of concentrated loads, followed by a uniformly distributed train load, and it was determined to make this arrangement of concentrated loads as simple as possible. To this end, diagrams were made up showing the equivalent uniformly distributed load per foot for various spans, that would produce the same maximum bending moments and shearing forces as our heaviest engines and train. Engines used by other roads were diagrammed in the same manner, also the typical loadings of various bridge specifications. The resulting diagrams were like Plates XIX, XX attached to this paper, which are copies of the Norfolk and Western Railroad standards. Such diagrams not only furnished a means to the making of our conclusions; but, also, means of properly presenting the matter to the management of this road.

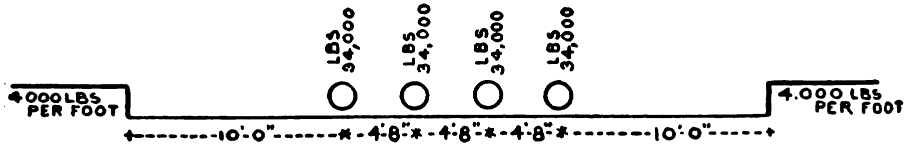


FIG. 1.

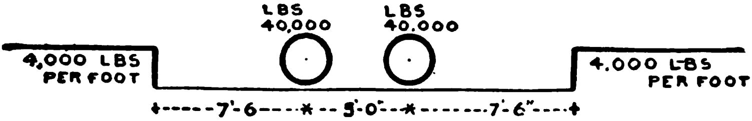


FIG. 2.

On May 1, 1889, standard specifications were adopted having a very simple type of loading, in form like those of our specifications dated January 1, 1891, but a trifle lighter. On January 1, 1891, specifications were adopted, having a loading as follows:

All bridges shall be designed to carry (in addition to the dead load) a live load of 4,000 pounds per lineal foot of track, of which 136,000 pounds is liable to be concentrated on four axles, as in Fig. 1, or 80,000 pounds to be concentrated on two axles, as in Fig. 2.

Plates XIX, XX clearly show to the eye what a uniform excess of strength we secure by this type of loading; in fact, for all spans the excess strength is practically 20 per cent. A large amount of bridge work has been erected by various bridge companies for the Norfolk and Western Railroad Company under this form of specifications during the last two and one-half years. All the bridge people have expressed themselves as pleased with the simplification secured by this loading; and, I think, we have taken a very long step in the right direction. Although the great simplification gained by doing away with the tender wheel load and adopting a uniform spacing of the four concentrated loads employed makes the direct calculation of the truss strains a comparatively easy matter, still further simplicity is gained in the calculation of all short spans and plate girders by the use of the equivalent loads appropriate for each particular span as given by the diagrams; and these diagrams having once been plotted, it has been our practice to use the equivalent uniform loads in this manner, with the result of a great saving in time.

The advisability of removing the tender wheels of the typical loading was made evident from the fact that the weights on tender wheels are no greater than the weights on wheels of loaded freight cars; and that the increased train load per foot, which it is now found necessary to adopt generally, more than covers any concentration to be found under our tenders. This plan of forming diagrams like the preceding originated with my principal Assistant Engineer, Mr. Morgan E. Yeatman. The requirements of the problem at hand speedily showed to us its uses and brought about the above results. There is no reason why, by the use of such diagrams, a simple type of loading, like that of our specifications, cannot be adopted by every railroad company to suit the requirements of their traffic. These diagrams are simply graphical representations of the tables of Mr. Waddell, and show the same result. I know it is the practice of several bridge companies to make just such tables as those of Mr. Waddell to conform to a given specification; in fact, the above-mentioned diagrams have been checked partly by a table from the Edgemoor Bridge Works. The rule mentioned by Mr. Waddell for finding floor beam concentrations has been used on this road for the last three years, and, like many other points, the proof of it was discovered through the use in bridge calculations of diagrams like those heretofore referred to.

I trust this discussion may be continued until it results in the entire abandonment of a multiple form of engines for use in bridge specifications; and I hope that the above statement will indicate the uselessness even of the six types of locomotives proposed by Mr. Waddell for this purpose. I would recommend rather the use of a uniform load with concentrations at not more than four points, which can be so selected as to cover the present and future requirements of the traffic of any railroad. The loading having been adopted, it is a simple matter to prepare diagrams to expedite the practical work of calculation of bridge strains.

By Robert Moore, M. Am. Soc. C. E.

Professor Waddell's remarks upon the unwisdom of adhering to the details of some actual or typical engine in determining the loads and stresses in railway bridges meets the writer's most hearty approval. The actual engine loads must, of course, be the ultimate standard of reference; but this is no reason for declining to use in all ordinary work a simple system of equivalent uniform loads; we might as well insist that all measurements must be made with the official standard yard.

When pressed for time in which to work out the proper equivalents the writer has specified the loads given by a particular engine; but when he had not this excuse he has specified a uniform load per foot with a single concentrated load to represent the excess weight of the locomotive, using one standard for the floor system which receives its full load with every locomotive; a second for the web system, in which the maximum stresses are developed by a partial load, and a third for the chord members, in which the maximum stresses are developed only by the full loading of the entire span. If Professor Waddell, or other parties interested, will work out a complete system of uniform loads equivalent to various actual or typical engines, to be selected or approved by a committee appointed by the American Society of Civil Engineers, the writer, with many others, will take great pleasure in abandoning the use of engine concentrations altogether. The writer also agrees quite fully with Professor Waddell's remarks upon suspended floors, and when, some years ago, a railway manager gave the writer for revision a bridge specification in which suspended floors were required in all cases, he amended it by forbidding their use in any case. This rule he has since had occasion to relax in but a single instance, and then for reasons purely local and special. The gain in lateral stiffness by the rigid attachment of the cross girders to the posts is so great as to justify this method, even at the cost of a good deal of attention to the connecting rivets, which, however, in the writer's experience, is not required. And if the attachment be made, as is now frequently done, by extending the web of the cross girder through a post made of Z bars, he sees nothing further to be desired.

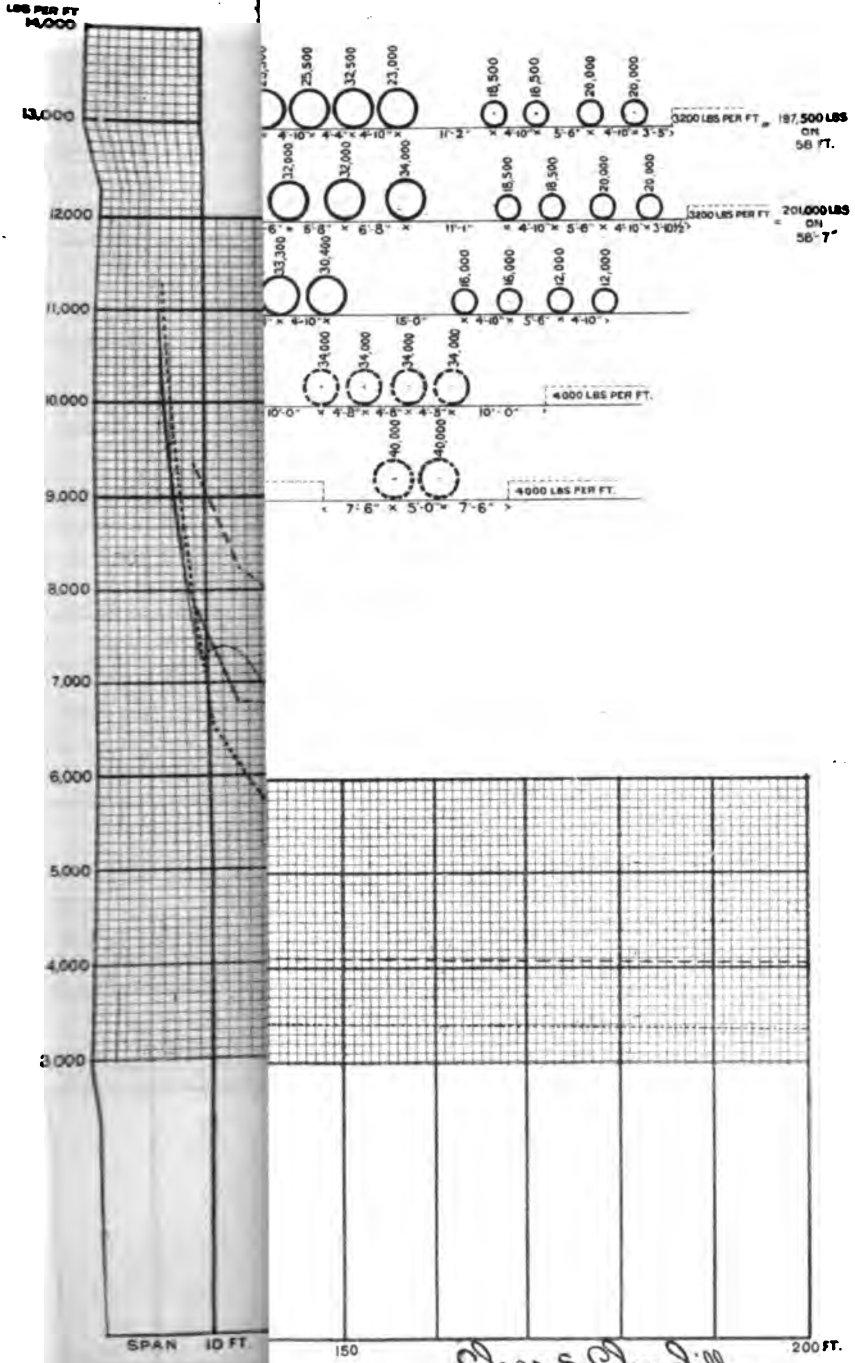
As regards the spacing of the stringers, the writer very strongly prefers to place them exactly 6½ feet between centers. With this spacing the outer guard rail can be fastened by hook bolts to the outer flange of the stringers at such a distance from the track rail (12¾ inches from the gauge side) as to insure that a derailed wheel will drop on the ties without climbing the guard rail, and yet keep at the greatest possible distance from the truss. By this arrangement the wider spacing of the trusses recommended by Professor Waddell is not required.

Referring to Professor Waddell's remarks upon the use of steel in bridge work, the writer fully agrees with him that, except for screw bolts and minor members, it should be insisted upon for all first-class work. When the utmost economy of time and money is demanded, the writer is sometimes forced to allow the use of iron—excepting for eyebars, pins, rivets and connecting angles—but he does it with great reluctance. But in using steel he differs from Professor Waddell in believing that the reaming, or, still better, the drilling of rivet holes after the parts are assembled, is something that ought always to be required. This should be done not only as a precaution against injury to the metal and consequent fracture, but more as a means of securing smooth and closely matched holes which the rivets can completely fill. In holes for field rivets, where tight work is so hard to get, the reaming is a matter of much importance, for iron no less than for steel.

By Mansfield Merriman, M. Am. Soc. C. E.

I agree with Mr. Waddell that the specification of typical locomotives with wheels whose distances apart are expressed in inches and fractions, or even in whole inches, is unprofitable. It is like computing the area of a circle with the value of π expressed to ten or more decimals when two or

PLATE XIX
TRANS. AM. SOC. CIV. ENG'RS.
VOL. XXVI. No. 522.
CHURCHILL ON
R. R. BRIDGE DESIGNING.



Chas. S. Churchill
OFF. ENG. M. OF W. ROANOKE, VA. 12.15.91.

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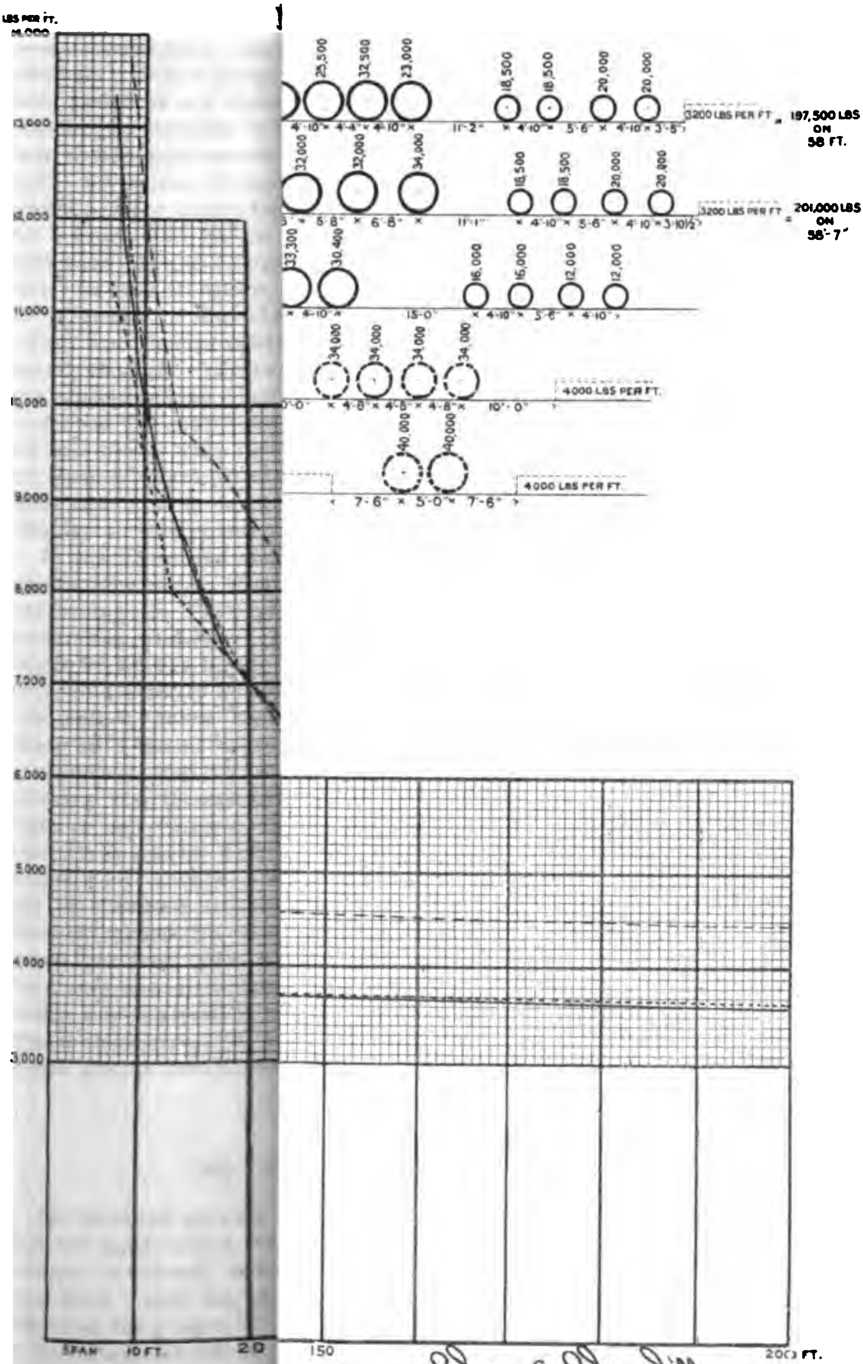
PLATE XX.
TRANS. AM. SOC. CIV. ENG'RS.
VOL. XXVI. No 522.
CHURCHILL ON
R. R. BRIDGE DESIGNING.



Chas. S. Churchill
OFF. ENG. M. OF W. ROANOKE VA. 12.15.91.

three would answer every purpose; indeed, it is worse than this, for in figuring on the circle a true result is obtained, whereas the typical locomotive gives stresses that can never exist. When, however, such locomotives are specified, it is the duty of the bridge designer to use them in his computations, and it is my opinion that usually it will be better to do this directly according to methods which are well known to be logical and accurate, rather than obtain equivalent uniform loads and then find the stresses due to these. Of course, errors of two per cent., or thereabouts, on the side of danger are not important, and I would not oppose the method proposed on this account, but there appears to be little gained in simplicity by its use. Computers should adopt the method which suits them best, regarding not merely saving in time, but also simplicity in the logical understanding of the processes. I should judge that most students would find the theory of concentrated loads easiêr to understand than that of computing and using several uniform "equivalent" loads to attain the same results. Those who write specifications and invent typical locomotives should be strongly urged to express the distances between the wheels in feet, or at the most in feet and half feet. This was done in Wilson's specifications for the bridges on the Pennsylvania Railroad published and discussed in Transactions for 1886, and if such were the case with all typical locomotives, most of the difficulty in computing stresses would disappear.

In the "Annales des Ponts et Chausses" for September, 1891, is promulgated a new order concerning the computation, design and testing of railroad bridges in France. It specifies a typical train load, consisting of two locomotives and two tenders, followed by loaded cars. Each locomotive weighs 56 tonnes on a wheel base of 3.60 meters, there being 4 axles equally loaded and equally spaced. Each tender weighs 24 tonnes on a wheel base of 2.50 meters, there being two axles equally loaded. Each car weighs 16 tonnes on a wheel base of 3.00 meters, on two axles. This is a very simple arrangement, and it is particularly praiseworthy in having no uniform load following the locomotives, all the cars being on wheels, as they certainly ought to be. "Logic is logic," and those who persist in specifying typical locomotives ought not to rest content unless the entire rolling load is concentrated on wheels. However, if a uniform load and a single concentrated load be specified instead of typical locomotive wheels, simplicity in every direction would be attained. The uniform load would range from 5,000 pounds per foot, per track, for short spans, down to 3,000 for long spans. The single concentrated load might be the same for all spans, say 100,000 pounds, and it should be given any position, either at the head of the uniform load, or elsewhere. I trust that the paper before us will lead to the adoption of such simple methods of loading.

By A. J. Du Bois, Jun. Am. Soc. C. E.

Mr. Waddell gives us a rule for finding floor beam concentrations directly from the equivalent uniform live load. For this rule he claims that "the principle involved was unknown to the engineering profession only two years since," and he declares that he is "amazed that the principle was not discovered long ago." The rule is thus put forward and emphasized by him as the statement of a new principle and a noteworthy addition to engineering knowledge. Mr. Waddell is an expert bridge engineer, and his record shows that he understands his business. To make a slip occasionally in a paper written under pressure is no disgrace to such a one; and if, therefore, I venture to point out a slip in this case, it is simply in the interests of accuracy. No one, I am sure, will be more ready to candidly acknowledge such a slip than the author of the paper under discussion, and few can better afford to.

Let me say then, that after careful examination of Mr. Waddell's demonstration of the rule in question, I fail to find any addition to our knowledge or any new principle. I do not even find any principle stated at all, but only the statement of a rule. Now a rule is not a principle, but the result of the application of a principle. The principle which lies back of Mr. Waddell's rule is apparently not recognized by him at all. Yet it is well known to him and to all of us. If it had only occurred to him, he could never have written about it or its consequences as he has. The application of this principle gives us immediately without the least algebraic work Mr. Waddell's rule, and in a more general form than he puts it himself.

By the expression "equivalent uniform load for a point," is always meant that uniform load which causes at that point the same moment as a given system of concentrated loads, to which the uniform load is thus "equivalent." Premising this, the principle which is really involved in Mr. Waddell's rule, which he has failed to use, but which is, however, long known to him and to all of us, is simply as follows: A uniform load causes the same moment at any point of a horizontal beam supported at the ends as half that load concentrated at the point. Mr. Waddell knows this as well as all the rest of us, and if it had only happened to occur to him, he would have saved not only all his algebraic work, but also his remarks about his rule, the ignorance of the profession up to that time of writing, the newness of his principle, and no little unnecessary amazement. He would have simply stated his result as a directly obvious conclusion, and made no further comment. For of course it follows at once, that if any given uniform load is the equivalent uniform load for any point of a span, half of it concentrated at that point and acting down, gives the same moment at that point as the given system of concentrated loads to which it is equivalent. If, however, it acts up, and the given system also acts, the moment at the point will be zero. In other words, the original span is now converted into two adjacent, independent spans, with intermediate support at the point, and the reaction at the point is equal to half the equivalent uniform load for that point for a span equal to the original span.

Here, then, is the rule more generally stated than Mr. Waddell himself gives it. He take his point in the center or supposes equal panels. This is not necessary. The result and principle hold good for any point, and are the direct and immediate result of a well-known principle.

When Mr. Waddell reflects that this is really the principle at the bottom of his unnecessary algebraic work, that he has actually gone through that work without recognizing it as an old friend, that it is really this principle which he claims the entire engineering profession were ignorant of two years ago—it is, I think, simple justice to him to say that his amazement will be no less than ours, and no less than it was before, although the grounds for it may be changed. It is indeed true that, so far as I know, his rule has never been explicitly stated before. But then, since equivalent loads can only be found when the reactions are already known, it naturally enough has not seemed worth while to any one to state how to reverse the process. If, however, the equivalent loads are given, it would indeed be a source of legitimate amazement to find any engineer at a loss to reverse the process, and I am sure it will now seem equally surprising to Mr. Waddell himself, that having thus reversed it, he should have for an instant thought that any new principle was necessarily involved in working a problem backward which was not already involved in working it forward, or that he was making any noteworthy contribution to engineering knowledge in so doing. It must also now seem equally surprising to him, how he could write that he had "just ascertained" that "equivalent loads can be used in finding the reaction"—knowing as he did that they can be found from reactions—and not at once see that it should have taken no time worth speaking of to ascertain that the reverse was also possible.

As to the use of uniform loading, with or without engine excess, in place of the present laborious, heart-breaking method of computing stresses, I wish to agree most emphatically with Mr. Waddell, and I sincerely hope that this discussion may lead to such reform. Nothing is more certain than that the stresses as now found for a specified wheel load system are not the exact stresses even for the system specified, and still less for other systems for which the structure must also be adapted. Any specified system is thus only typical, and intended at best to give stresses greater than any actual loading, present or future, which the structure may have to carry. Impact has to be allowed for even then, and thus the apparent accuracy is a delusion. It is also certain that uniform loadings, with or without engine excess, can be easily chosen so as to give always a very close approximation to the stresses due to any assumed system as at present found, and in nearly every case somewhat in excess, as they ought to be. Scientifically, there is no reason for preferring one method to the other. Both are approximations, both are in error for the same reasons, and both give essentially the same stresses. Ease of calculation should therefore decide the matter. The present method can claim no advantage over the other, and is incomparably more laborious and time wasting. The writer has been obliged to teach and use it simply because it is in vogue. But he still retains and teaches the other also, believing firmly, as he has long since stated, that sooner or later engineering practice will return to it. May the day be hastened! The present tedious method is not so new as seems to be supposed. It may be that when those responsible for it find that they have been anticipated, so far as discovery and introduction is concerned, they may be less interested in their fad.

Long before 1879, Professor Asimont, of the Munich Polytechnic, taught, and in 1879 he published the identical method which was worked out independently here in 1880. Professor Asimont's diagram is in a different and much less convenient shape from that usually employed here, but the method is precisely the same. So far as priority of discovery and publication is concerned the method is his and should bear his name. I received Professor Asimont's method in July, 1879, and after examining it laid it aside as a defective refinement, offering only apparent accuracy at the expense of unnecessary labor. Such I still consider it, under whatever name it goes. If I had been told in July, 1879, that in a few years it would be specified here by our railroad companies and advocated by our most eminent builders and designers, I would have listened in utter incredulity. I would have replied that our designers have left that sort of investigation exclusively in the hands of "theorizers," the "mathematicians," the "x, y, z engineers." That in America that sort of thing wouldn't "go." That our "practical" men would regard such investigations as an outcome from that scholastic Nazareth out of which in their opinion cometh no good thing. That they were the last men in the world to look with favor upon scrupulous refinement in calculation, the accuracy of which was neutralized by fundamental ignorance of the actual conditions. That, in short, they would care little for a laborious method of calculation, the validity of which was impaired in the start by unknown factors not accounted for. And yet since then that very method has become the fad of the day. If to get up an elaborate mathematical treatment which goes farther than actual conditions warrant is to theorize, then the theorizer leads the crowd to-day. The method "goes," and, as in duty bound, I have had to teach and use it—but always under protest. I have never had a student whom I have not encouraged to do his best to show it up. I am rejoiced that at last the time seems getting ripe for a general protest all along the line. I hope it may be so general that it will have to be regarded, and so forcible that it will be effectual.

Gentlemen of the Asimont method, the present paper makes a square issue. It has been made before and has been ignored every time. Mr. Waddell is not the first by any means to show and prove that for any given wheel load system you please uniform loads, or uniform loads and the engine excesses, can be specified, which will in all cases give stresses almost identical. That, considering the necessary inaccuracy of the present method, no man can say that these stresses are not every whit as accurate. They may even be more so. They are in general slightly greater, and they ought to be. I object to Mr. Waddell denoting errors on the wrong side of the present method by the word "danger." It is an unnecessary concession. It would be as just to make the other method the standard, and to denote errors on the wrong side of it by "danger."

Here, then, is the square issue which has been so persistently ignored. Are those deviations from the results of the present method, small as they are, on the "danger" side or not, and are they worth the drudgery of their evaluation? If so, your reasons, gentlemen of the Asimont method! If they are not, why in the name of common sense must we continue to submit to such drudgery?

By J. P. Snow, M. Am. Soc. C. E.

I am glad that the subject of bridge designing is again before the Society for discussion. I consider Mr. J. M. Wilson's paper on "Specifications for Strength of Iron Bridges" and its discussion, published in Vol. XV of "Transactions," page 389, the best treatise on details of bridge design that has been published in the English language. A full discussion of the present paper will be of great value as supplementing that and bringing it to date. The practice of using uniform loads for calculating strains seems to be making substantial progress. This is as it should be, and is a natural result of the fact that bridge buyers are getting more and more to make their own designs. Calculating by wheel concentrations was a great step in advance of the old method of using a certain uniform load per foot for all spans, and it still gives the chief engineer or manager, who does not know how to design his bridge, and who does not employ an assistant who does know how, an easy and precise way to specify for the bridge that he wants.

It is really more complex to specify how a bridge shall be designed for uniform loads than it is to say, "All parts of the structure shall be calculated to resist the maximum strains produced by a string of class so and so engines." On the other hand, in designing the bridge, it is much simpler to use uniform loading, that is, the bridge buyer who does not know how to design his bridge had best specify the engine diagram. If he attempts to specify uniform loading he must state carefully how it is to be used for chords, shears, stringers, floor beams, etc., and the chances are that he will either make a botch of it or leave bidders much to assume at their individual convenience. In the nature of things, typical engine diagrams and standard specifications, so-called, are not for engineers who know how to design a good bridge in their own right.

For the past seven or eight years, that is, since I have been a bridge buyer, I have used uniform loading exclusively, and see no reason now for doing otherwise. I do not object to the amount of labor per se involved in calculating by wheel concentrations, but it violates one of the fundamental precepts of good engineering to put so much more precise and laborious work into one part of the design than into another; that is, the labor of making a strain sheet ought not to overshadow the using of it. At present I am using a live load curve giving loads as below:

Span	Load per foot	Span	Load per foot	Span	Load per foot	Span	Load per foot
4	30 000	12	10 430	30	7 280	80	4 750
6	20 000	14	9 700	40	6 380	100	4 460
8	15 000	16	9 180	50	5 710	120	4 360
10	12 000	20	8 470	60	5 270	150	4 340

It is based on a string of consolidation engines with 35,000 pounds on each driving axle and a tender with 20,000 pounds per axle; to this is added $\frac{25{,}000}{\text{span}}$ to cover the imperfections of track, wheels, etc., generally denominated impact. The short span end of the curve is touched up with a pair of axles 8 feet centers, with 45,000 pounds each plus $\frac{30{,}000}{\text{span}}$. I take issue with the author in thinking this latter engine should be used, as more than half the bridges with which I have to deal have spans less than 20 feet. To state how the above loads are used for moments, shears, floor beams, stringers, reactions, etc., would be too long for this place; but if the author of the paper will look up a communication from me published in Railroad Gazette, December 10, 1886, he will see that his claim that no one knew of the principle which demonstrates that the floor beam load is equal to the panel length multiplied by the load per foot, corresponding to a span of twice the panel length, is a bad one. I there say, "For floor beams use $l \times$ load per foot corresponding to span $= 2\,l$, where l is the panel length." The editor of the Gazette volunteered a parenthesis which marred the sense, but the above are the words as written. I have used this "principle," constantly, since 1884.

A bridge that is unsatisfactory to the trainmen who use it and the bridge crew who take care of it is not a good bridge, although it may satisfy the engineer who computes it. The converse of this statement, however, does not always hold; that is, a bridge may be satisfactory to the men who use it and take care of it, and still may have some glaring fault of design that causes some part to have but a fraction of the strength of the other parts. Still, the bridge engineer, if he wishes to escape being called a crank, must be very cautious in condemning a bridge on the score of unscientific design, that is doing its work in a satisfactory manner; especially if he be not the possessor of a gray head. Riveted pony trusses of 90 feet span can be made perfectly satisfactory, and careful study of many of them under the action of trains convinces me that if properly designed they make good bridges. I prefer them to through plate girders of that length, from the fact that such heavy girders are very likely to get badly abused in getting them into place. For deck spans the whole can be riveted at the shop, and the handling is then a simple matter and can be done without injury to the iron work. The very best form, in my opinion, in which metal can be put to make a bridge, is a deck plate girder with cross floor beams and stringers; the stringers to be under the rails and their tops to be level with the tops of the girders; the girders to be spaced as wide as can be shipped on cars. I have no trouble in getting them 9 feet on centers. In this form of bridge the girders support the ends of the ties and the latter project outside of the girders sufficiently to allow convenient bolting of the guard timbers. I have designed very many multiple system riveted trusses, and the only substantial objection to them is that symmetrical chords with channel-shaped sides cannot be used. I have dropped them for this reason. For a web system simply the double cancellation is far preferable to the pure Warren type, and more economical. Do we not use it continually as the best lateral bracing that we can devise?

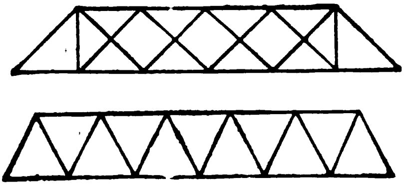


FIG. 1.

In the six-panel truss shown above, the double system has the same number of web members as the Warren, and the shear in each of the former is but approximately half what it is in the latter. The inclination and length is greater, to be sure, but it will work up more economically if five-sided chords can be tolerated. The ambiguity as to which system the one-sixth of an end panel load travels over to get to the farther abutment is of but little moment. If the designer is very thin-skinned he can allow for it on both systems. A modified Warren, as shown below, has many advantages, and I am now using it exclusively on short spans.

I would use pin connections for shorter spans than the author names. A double track span of 100 feet makes a good solid pin bridge. I agree with the author in his condemnation of suspended floor beams and concerning rigid bracing. The specification under which I am now working says: "Floor beam hangers free on the pin will not be allowed;" and "The laterals in the loaded chord shall in all cases be rigid bracing." Regarding bridge floors, the prac-

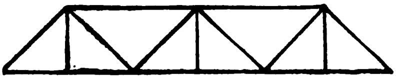


FIG. 2.

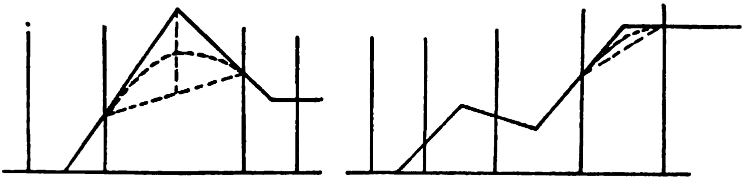
tice on the system with which I am connected is to use flat ties 6 x 8 inches on wooden bridges, and 7 x 8 inches flat notched one-half to three-quarter inch over the stringers on iron bridges. These ties are 12 feet long and laid 12 inches on centers; guard timbers 6 x 8, notched 1 inch over the ends of the ties and bolted to every fourth tie. Our main stringers are 5 feet on centers, without outside stringers in through bridges 10 feet wide. I prefer Southern long leaf pine for bridge ties. It outlasts the hard woods and shows plainly when it is decayed. I object strongly to the wide spacing of stringers advocated by the author. If we are building an iron or steel bridge, let us make it complete in itself, and leave the ties to do only their legitimate duty of holding the rails to gauge and line. The idea that some engineers seem to have that the wheels should be cushioned by the spring of the ties between the stringers belongs on the shelf alongside of the old idea that iron bridges must be set on wooden wall blocks, that they would be shattered like glass beads if they rested directly on the unyielding masonry. I know of no instance where the flange angles of stringers have been bent down from the deflection of the ties, but can remember two bridges where ties have been found broken on account of the wide spacing of the stringers, and this by trains on the rails. No doubt the ties mentioned were cross-grained and not large enough, but the design is poor that looks to the rapidly decaying ties to help out a floor beam of scant dimensions. In New England a great majority of the bridges are limited in the matter of depth of floor, and the necessity of using a deep tie would often interfere with making a good design. The thickness of tie named above is sufficient to take the spikes, and experience shows that they last as long as larger sticks. Personally, I should place the ties farther apart, say 14 or 16 inches. I have known many instances of derailed cars crossing bridges with the latter spacing and there was no bunching of ties. I abandoned the practice some years ago of bolting the tie floor to the iron work. If the ties are notched over the stringers and the guard timbers over the ties, there need be no fear that the floor and bridge will part company, unless it be in a cyclone region, with which I confess I have had no experience. On our wooden bridges the ties are not notched, but are planed one side to even thickness and spike bolted to the stringers.

"Impact" and "fatigue" measure the bulk of our modern ignorance in iron bridge designing; they are the present-day representative of the old bugbear that used to be downed by the "factor of safety." It seems reasonable that "impact" should be covered in the loading, and the addition to the engine loads previously mentioned is my attempt to do this. As a matter of fact, the deflection of a bridge, even though it be of very short span, is but slightly more under fast speeds than it is if the engine stands on it at rest; this depends, however, on the condition of the track surface and also on the wheels. I have known freight cars at speed to deflect a bridge more than the engine, evidently on account of wheels which were worn out of a true circle. "Fatigue," if we believe in it, should be covered in the unit strains. That the deductions from the German experiments on the effect of oft-repeated strains on metals are not applicable to bridge designing as stated by the author I thoroughly believe. Still, supposing our strain sheet to show the true relation between the strains in all parts of a structure, it does not seem satisfactory to use a constant unit for both those parts which are loaded to their calculated maximum at every passage of a train and other parts which get their maximum only under the unusual circumstance of two typical trains meeting. Nor does it seem just right to use the same tension unit for parts which are strained from zero to the calculated maximum many times a day, and other parts in which the varying load is no more than perhaps 50 per cent. of the total. That oft-repeated strains within the elastic limit hurt a member in compression, I do not believe. My practice is to use 10 per cent. greater unit strains on the middle truss of a three-truss bridge than on the side trusses, and for general tension a curve the ordinates of which give tension units, the abscissas being values of $\frac{\text{min.}}{\text{max.}}$. This curve might as well have been sketched by eye through certain points that were assumed as satisfactory as to have been constructed from an equation. It seems to me that a curve should be more satisfactory to use than a list as suggested by the author, which jumps 1,000 pounds per inch between long and short members.

I see no sound reason for assessing plate girders below 20 feet span, as recommended by the author. His desire to discourage the use of short panels by so doing is hardly good engineering; the panel length, unless governed by head room considerations, should be a function of the truss depth and distance between trusses. In short spans we are right in using short panels; and as stated before, more than half the bridges under my care are less than 20 feet span. We cannot discourage these legitimately by such units. The practice with us is to use one-sixth of the web as flange section in plate girders when the web is in one sheet without splice; but if the web is in several sections and the splice plates are proportioned only for shear, it seems hardly justifiable to count much on it to resist deflection. I do not understand the reason for the author's statement: "Of course if the web be counted in, the intensities of working stresses of the flanges will have to be decreased accordingly." In my judgment the plate girder is the best form in which we can build up metal to carry a load across an opening, and I allow the same tension units in them that I do in eyebar members of a truss. I find that nothing less than three-eighth webs in stringers will give proper bearing for rivets. The wheel load cannot be reckoned as producing less than about 2,500 pounds vertical pressure on a single rivet, and this, combined with the horizontal pressure from the flange strain, will call for a three-eighth-inch web, at least, in the majority of cases. The fact is, good machine-driven rivets are worth more than we generally allow, but if we have a set of bearing units we should take account of all the loads coming on our connections and stick to them. End floor beams are a good detail if the stringers are extended beyond the beam enough to take one tie; otherwise the distance between the last bridge tie and the first ground tie will be too great.

In calculating pin moments I think the load delivered to the pin by each member should be considered as distributed over its thickness. It surely is so distributed in fact. If the maximum moment occurs at the middle of the pin the result will be the same whether the load is so considered, or concentrated at the center of the member, but if the maximum occurs under some particular bar, the above consideration reduces the moment sometimes quite materially.

In the moment curves sketched below, the full vertical lines represent the sides of members packed on a pin, the full broken line the moments calculated with all load concentrated at centers of members, and the dotted curves the allowable change if the loads are considered distributed. It will be seen that the reduction is one-half the distance from the vertex to the line joining the intersections of the sides of the bar with the moment line. In some cases this perfectly legitimate consideration will materially help out on the size of the pin.



It is not likely that the discussion of Mr. Waddell's paper will exhaust the subject so that there can be no more said. Each one can state his opinions and beliefs, but it is not good manners to insist that others shall believe our creeds. My rules and methods are for my office; I will not attempt to force them on brother engineers. If they like them they are at liberty to use them. If they do not believe as I do, I dare not say they are wrong.

By W. R. Hutton, M. Am. Soc. C. E.

On the resistance to bending of the web of a plate girder.

FIRST.—First as to our author: He proposes to add one-sixth the area of the web to each flange, and to decrease "accordingly" (i. e., proportionately) the intensity of working stress. As the result in this case will be the same as if the web were neglected, it is difficult to see a reason for it.

SECOND.—It is well known that in a rectangular beam the maximum shearing stress is about the neutral axis, diminishing to zero at the top and bottom fibers. In an I beam it is more nearly uniform throughout the web; still almost nothing in the flanges. Beyond question, then, the web must take the entire shearing stress.

THIRD.—As to the bending stresses in the web, they exist and cannot be got rid of. Their intensity may be reduced by increasing the area of the flange, and this, in fact, is the practical effect of neglecting the web in computing the resistance of the beam. It would seem to be more rational as well as more exact to consider the entire section and proportion it for such intensity of bending stress as may be best for the particular case. The former method is an additional factor of safety, of variable, and, perhaps, uncertain value in ordinary practice, but there are cases, as mentioned by our author, in which it cannot be applied.

FOURTH.—The progress of exact methods is well exemplified in our author, who, a few years ago, was a partisan of the flange-only-for-bending theory in its most extreme applications. We welcome his change of mind.

FIFTH.—The proportioning of flanges to take the whole bending stress, while the web takes the shear, is not uncommon with French contractors. The following line of reasoning in support of the practice is from one of their authors. The moment of inertia of the beam enters into the formula for maximum shear. Now, if we use the moment of inertia of the flanges alone, neglecting the web, it results that the shear is evenly distributed over the section of the web. In other words, if we assume the bending stresses to be borne entirely by the flanges, it follows that the shear is uniform throughout the web.

By W. L. Cowles, M. Am. Soc. C. E.

There are a few portions of Mr. Waddell's paper to which I would like to add emphasis while heartily approving nearly all the suggestions made. With regard to the using of uniform live loads, there can hardly be any question that any provision whereby the labor of computation can be decreased, while at the same time a satisfactory approximation to accuracy is reached, will meet with the approval of all engineers; as the only result will be to lighten labor, and thereby decrease cost. This is a matter of more importance to the computing engineer of a bridge company than to the engineer of the railroad for whom a design may be prepared, as the direct cost to the railroad company is not affected materially by the difficulty of making the computations after a specification which may be new to the designer, and the engineer of the railroad having always to use the same specification, can prepare tables which will make the work of checking and designing simple for himself; but there would be an indirect gain to the railroad company through the decreasing of the cost of designing, which must in the end be paid for by those who buy the bridges. It is impracticable for the computer of a bridge company to make tables which will fully cover all the different specifications now in use by different railroad companies, although some of the most common can be provided for in this way. It certainly can occasion no additional labor on the part of the railroad engineer, and will surely lighten the labor of the computer, if a system of uniform live loads such as suggested can be universally or even widely adopted. When it is considered that the engine and train loads on any given road differ very widely, and that the specifications for bridges are, or should be, so written as to provide for the very heaviest load, with something of a margin for possible increase in the future, it seems that there should be no objection to adopting a uniform load which will give strains within a reasonable per cent. of those caused by the heavy typical load, and the result of Mr. Waddell's investigations seems to indicate very plainly that such loads can be determined and used without the large number of different assumptions which have been considered necessary.

In the tables presented on pages 269, 270 and 271, it will be observed that the error on the side of danger is rarely much over 2 per cent., and it may be well to call attention to the fact that as this is for the live load simply, the actual error on the side of danger in the resulting section will only be from 60 to 70 per cent. of this amount, or 1.2 to 1.4 per cent. altogether, since the dead load can be calculated accurately. In case it were deemed essential that there should not be even this per cent. of danger, it would be easy to estimate the percentage to be added to different members of spans of varying numbers of panels which would make the strains right, as these percentages would be practically constant for spans of the same number of panels, and they could be easily applied. This, however, would be in the direction of additional work which it is sought to avoid, and an easier method would be to make such an addition to the assumed uniform load as would cause all results to be on the side of safety as referred to that load, which would be equivalent to a satisfactory concentrated loading. It may be objected that this would add materially to the cost of the bridge, but upon investigation it will be found that the difference is not great. In tension members, where the area cannot be provided for exactly by ordinary regular sizes of bars, the difference arising from using an extra 2 per cent. is rarely such as to cause a difference in the size, and will sometimes be provided for by the excess of section used, and generally will not increase the section enough to add to the thickness of the bar, although in a few cases it may have this effect. In compression members where it is customary to make the sections exact by varying the weight of channels or angles, there will be some increase of section, but the amount is indicated by the result of a calculation on the 300-foot span mentioned on pages 270 and 271, where the total additional cost was less than $40, an amount which a railroad engineer might be willing to pay in one or two cases for the advantage of a uniform system of loads.

I cannot pass the section concerning forms of trusses without expressing my thorough approval of Mr. Waddell's objection to pony trusses. The uncertainty with regard to the strength of the top chord and the lack of rigidity in the structure should cause every engineer to discountenance its use. I cannot quite agree with the writer in his opinion that it is better to carry the intermediate panel load of a Pettit truss by a strut toward the pier instead of a tie toward the center, although I am willing to admit that the former method will give somewhat more of inertia and consequent rigidity to the truss, for the reason that in the center panels the dead load strain, carried to the top of a post by the tie referred to, is generally necessary to prevent reversal of strain on the post at a point where the line of the top chord is broken. This I consider is essential to avoid if possible, and I think this is more important than the slight additional rigidity afforded by the strut.

I am glad to notice that the question of unit strains on end posts is mentioned, as it has always seemed to me that it should be regarded as a continuation of the top chord system rather than as an intermediate post. The reason for Mr. Cooper's specifications for this member, I have understood, was to provide additional section and weight as a means of resisting any possible shock or blow from a passing train which might be derailed at that point; but this can be much more effectually provided for, if, indeed, a bridge should be designed to resist such a shock, by adding a collision strut running from the center of the end post to the second bottom chord panel point; and this construction, in addition to providing for this contingency, assists the end post by decreasing its effective length, and thereby stiffening it and decreasing its section. Another consideration against using so small a unit strain in designing the end post is that, as fully shown by Mr. Waddell, the end post should have ample provision for carrying the bending strains induced by wind pressure, and if designed with this in view, will certainly be heavy enough to satisfy any feeling that it should have excessive strength to provide for such a shock or blow as suggested. I believe that the end post should always be calculated to resist the bending moment referred to, although I cannot say that it has been my practice to do so, except where such provision is called for definitely in specifications.

I do not consider that a bridge is in danger if the end post is not thus designed, except for especially long spans, and it will hardly be expected that such a large amount of extra material as is required in such a design will be provided by a bidder in competition where it is not called for, unless in a bridge where its omission amounts to a danger. I think bridge builders would prefer to build work designed in this way than to build a lighter section, and this is therefore a matter for the railroad engineer who prepares the specifications, and I would be pleased to see such a specification become universal. The general specification that all wind strains shall be provided for is not sufficient to cover this point under the present practice in designing, and it should be made a special point. One difficulty which competitors have to meet is the uncertainty as to whether the engineer who compares their plans and checks them over is sufficient of an expert in bridge work to notice defects of this kind in any designs when such points are not particularly noted in the specifications. It is well understood that while many railroad engineers may have the highest ability in many directions, they are not necessarily experts in this line, although many are, and it is therefore extremely desirable that there should be confidence on the part of bidders that all plans would be examined by some engineer thoroughly competent to examine into all details of the designs and form an accurate opinion as to their relative merits.

The question of connection of stringers to floor beams is an important one, and the objection to riveted connections is a valid one, both on account of the horizontal bending induced in the floor beams, and also the tendency to cause the stringers to act as continuous girders, producing tension on the rivets at the top of the connection. The point in some specifications requiring that the connecting rivets shall all be included in the lower two-thirds of the beam avoids this danger largely, and is a good rule, although sometimes difficult to follow unless the stringers have considerable depth. The same objection applies to stringers resting on the top of the beam, where they should be braced in some effective manner, and where, if both stringers are attached to the same brace, there is a similar strain on the rivets at the top of the beam. In such a case each stringer should be separately braced, so that there may be no pulling apart at the tops.

By Paul L. Wolfel, Assoc. M. Am. Soc. C. E.

Professor Waddell objects to the use of concentrated loads for computing the live load strains in bridges, and prefers to use uniform loads per lineal foot, changing with the length of spans. While I can see no practical objection to this, I must object to his reason, viz.: that the use of concentrated loads involves a larger amount of labor and complications than uniform loads. By applying the modern graphical methods (moment curve, shear curve and secondary shear curve), such as have been in use in the Engineers' Office of the Pencoyd Bridge and Construction Company for many years, there is practically hardly any difference whether we figure with concentrated or uniform loads, and we can use them in all cases, as it makes no difference how many wheel loads may leave the bridge. With a little practice one can easily get all the live load strains for a six or eight panel bridge with straight cord in about one-half hour; for a curved chord, single intersection bridge in, say, one and one-half to two hours. I admit that there are a few cases, like draw-bridges and arched ribs, where we save time by using uniform loads, and where we are the more justified in doing so, as the assumptions upon which our calculations are based are more or less arbitrary. The proof given, that the equivalent uniform load for floor beams is the same as that for the center moment of a span equal to twice the panel length, is mathematically very interesting. This fact, though, has been known and taught in our engineering schools for many years; anybody familiar with the use of curves of influence must know it. As the floor beam reaction and the center moment of the above spans have the very identical curve of influence, the equivalent uniform load in both cases cannot help but be the same.

I cannot agree with what is said in the paper in reference to plate girder webs. I admit that it will be hard to prove that the failure has been caused by using too thin webs. The working stresses in our structures are in general so far below the elastic limit that those cases where a bridge fails by the weakness of the body of the member are very rare, and eventual failures can usually be traced to faulty construction of details and weakness of the connections. The shear in the web of plate girders, however, is just as much there as the strain in the web system of a pin or lattice bridge. Very often, though, it is misunderstood, as we see clearly in some specifications, like those of the Pennsylvania Lines west of Pittsburgh, which allow 4,000 pounds shear when the fibers are vertical and 5,000 pounds when they are horizontal. This ought to be just the reverse. If we say that the shear is transferred by the web only, we give an empirical rule, nothing else. This shear, as vertical shear in the web only, does not exist; it is taken up by the flanges just as well; but a shear equal to this exists in the middle of the web as horizontal shear, as we can easily prove theoretically. If we put two beams loose on top of each other, and let them deflect under a load, they will slide on each other. To make them work as one beam we have to apply horizontal tensile and compressive strains, which are nothing else but the horizontal shear in our girders. In plate girders not too deep I very often prefer even to use a heavier web and leave the intermediate stiffeners out altogether. In many cases this will not only simplify the shop work without weakening the structure, but also give a lighter and stiffer structure. The heavy web will help diminish the deflection; the stiffeners will not.

I heartily approve of what Professor Waddell says in reference to end stiffeners, as I know from my own experience that this is a point which is very often not called for in the specifications; and thanks to the customary lump sum bidding, is therefore often not considered by competing bridge companies. I also thoroughly agree with what is said on wind pressure, as Mr. Cooper's specification gives for long spans decidedly too low figures. The author states that the fatigue formula for bridge members is unnecessary, because the metal in bridge members has time to recover itself between the applications of live load. It may be worth while to draw attention to the fact that Professor Bauschinger's experiments have clearly proved that there is no such thing as fatigue of metal within the elastic limit; that you can load and unload a piece of metal below the elastic limit as often as you want without being able to break it. As all our working strains are below this limit, we can see that we need not consider fatigue of metal as such at all. Nevertheless, the fatigue formula, as Mr. Wilson has used it, for example, for the Pennsylvania Railroad Company's specification, is a very practical formula, and gives very good proportions, allowing higher strains for long spans and lower strains for shorter ones.

We determine our sections usually by the dead and live load strains only. The impact strain is just as important. It is usually only considered indirectly in most specifications. These impact strains will occur in the structure whenever a train goes over, and yet I am sorry to say that we know very little about them. The fatigue formula partly provides for it, as does Mr. Cooper in his specification, by allowing twice the permissible strain per square inch for dead load he allows for live load, or, in other words, by adding 100 per cent. of impact to the live load throughout. It is generally known that a short span, or a member whose maximum strain is produced when only a short distance is loaded, must get more impact than the long span or corresponding member. The load comes on more suddenly, and will in its effect be nearer a fully dynamically applied load. The vibrations, horizontal and vertical, while the load goes over, are more likely to add together for a few wheel loads than they will for a very long train, where probably quite a number will compensate each other. Mr. C. C. Schneider, in his specifications written for the Pencoyd Bridge and Construction Company, provides for that by allowing different percentages of impact for different lengths of loading. This seems to me a step in the only right direction. We can only determine the exact proportion of the impact for different lengths of loading by a series of experiments, which could be made without too much difficulty.

Prof. Dr. Fraenkel, of the Royal Polytechnicum in Dresden, has constructed a very ingenious instrument with which we can measure fiber strains down to 85 pounds per square inch, and which draws out a complete diagram of the strain in the fiber. Let us now figure the strain in a member for the most unfavorable position of a given load. Let us then apply this loading statically in the same position on the bridge, and measure the strain. Let us further run it over the bridge with different velocities and measure the strains again, and I think we would have no difficulty in getting at a fair average for impact and vibration for different spans and velocities, upon which, undoubtedly, the condition of the track and the rolling stock would have some influence. We could even go further than that. Let us measure the fiber strains in four points of a chord or post, and we can find out at the same time what bending stress our chord or post got from eccentricity and stiffness of the connections. Connecting our instrument with the lateral system, we can see what lateral stress the train produced in our structure. I have used these instruments with great success in many cases, and am convinced that we should see a great deal clearer in regard to many important and doubtful points, if some prominent bridge company or railroad company would take up a series of experiments in a systematic and scientific way. The question of impact settled, a great deal would be gained. If we knew from our dead load, live load and impact the greatest direct strain a member could get, we should surely much sooner be able to settle on a uniform permissible strain with a fair allowance for secondary stresses and safety; not for main members only, but also for the connections; for if we allow different working stresses in different members, we should surely do the same in our connections.

We could make, then, such assumptions for the lateral forces that we could use the same permissible strains also for our lateral system; and in this way surely simplify our calculations, and come nearer the ideal structure, in which all parts and connections are uniformly strong. Mr. Cooper says in his specifications that the rivet shear shall not exceed 7,500 pounds per square inch, or three-quarters of the allowed strain per square inch upon the member; the pressure on rivet and pin bearing not to exceed 12,000 pounds per square inch, or one and one-half times the allowed strain per square inch on the member. According to this, 7,500 and 12,000 pounds would be the upper limits, and the second conditions would only be used whenever they would give smaller values. I do not think that this is quite the intention of the author. A member strained with 10,000 pounds per square inch corresponding to the maximum shear of 7,500 pounds surely ought to have its connections designed with a smaller permissible shearing stress than a member strained with 15,000 pounds (laterals and members strained by dead load only). Why should ten rivets in single shear in one case be equivalent to 4½ square inches of metal, in the other case only to 3? Another disadvantage is that we make our calculations unnecessarily complicated by introducing two conditions. Very often we have to consider two cases, and must, besides this, figure out the average stress per square inch in the member especially for the purpose, as the section of the member is determined by the different strains for dead and live load.

For pin bending, Mr. Cooper allows 15,000 pounds all the way through. A 3 x 1-inch eyebar as a member of the lateral system is worth 45,000 pounds. In a short truss where we would get about 10,000 pounds per square inch, we have to use a 5 x ⅞-inch bar for the same stress; the same pin would, under the same circumstances, otherwise do for both these bars. Mr. Wilson determines his shear and bearing stress in proportion to the compressive unit stress in the members, at the same time allowing a constant fiber stress for bending on pins. This somewhat complicates the calculations, and is under the same disadvantage in so far as pin bending is concerned as Mr. Cooper's method. As soon as we make our bearing and shear dependent on the varying unit stresses in the members, we give up the great advantage of tabulating our shear and bearing values of rivets and pins, and have a great deal of mechanical work to do over and over again. All this is avoided in Mr. C. C. Schneider's (Pencoyd) specifications, where we figure with a maximum stress containing different amounts of impact for different lengths of loading, and use constant unit stresses throughout for main sections and connections. This is a point in saving time which, I think, is more important than the introduction of equivalent uniform loads as proposed by Professor Waddell.

Professor Waddell declares himself for figuring with high permissible strains, at the same time assuming the highest possible load a structure can get. I thoroughly agree with him on that. As the impact, however, is one of these strains, let us try to find out something more about this yet unknown quantity, introduce it in a scientific and yet practical way in our calculations, and by thus reducing our factor of ignorance allow higher strains. In determining our permissible unit strains, we ought to consider the secondary bending strains our members may get from the stiffness, and eventually from the eccentricity, of our connections. Even with central connections these secondary strains may be very considerable. We can reduce them to a minimum by proper designing and by selecting the proper systems. Prof. Dr. E. Winkler ("Theory of Bridges—II," Vienna, 1881) investigates a double intersection lattice girder of about 90 feet with a maximum eccentricity of only three-sixteenths inch for a load in every other panel point. Although this extreme case is not likely to happen in practice, we may draw some conclusions as to the relative value of different systems from his figures. He gives us the additional secondary bending stresses expressed in percentages of the direct stress, as follows:

1. Girder without verticals, diagonals connected at intersections: chords, maximum 113 per cent., average 65 per cent.; web members, maximum 90 per cent., average 36 per cent.; total average 51 per cent.
2. Girder without verticals, diagonals not connected: chords, maximum 88 per cent., average 68 per cent.; web members, maximum 25 per cent., average 18 per cent.; total average, 45 per cent.
3. Girder with verticals, diagonals not connected: chords, maximum 19 per cent., average 12 per cent.; web members, maximum 30 per cent., average 13 per cent.; total average, 13 per cent.

Even for all panel points loaded, these additional strains average about 12 per cent. in the first case. In a trestle bent I found the same figures for some members to be as large as 200 per cent. for central connections and nearly 300 per cent. with eccentricity. ("Civil Ingénieur," 1887.)

These secondary strains often cause quite peculiar effects. I remember the case of a suspension bridge, where the cables were made of pins and eyebars. Experimenting on them with Professor Fraenkel's instrument, we found compression in some of these bars when a heavy street roller passed over. A second instrument applied to the other side of the bar showed the tension, which we had figured, proportionately increased. We had a clear case of bending in our cable, caused by the friction of the pins in the pinholes. The whole cable, from the abutment over the piers to the other abutment, worked not only as a tension member, but at the same time as a continuous girder; so that while the additional strains produced by the street roller in the upper and lower fibers of the eyebars in the middle of the span were compression and tension, our instruments showed them to be tension and compression at the piers.

The question whether it is correct to apply different formulas for buckling for fixed and hinged ends, is a very difficult one to decide. All our buckling theories and experiments are more or less uncertain. All experiments refer to the ultimate strength. It would have been of much more value to us in those experiments had we known any fibers were strained beyond their elastic limit. Experiments of this kind could be made with the same instruments I spoke of in connection with the impact.

But even supposing we had derived a really perfect formula from our experiments, is there not quite a difference between the member with fixed ends in our testing machine and the same member in a bridge, where the stiff connections may not only not prevent the buckling, but where the secondary bending stresses, which are caused by these stiff connections, may even start the same? I think it hardly worth while, therefore, to make a distinction between fixed and hinged ends. Mr. Cooper gives different formulas for chords and posts, as I understand, to provide for the strains the posts may get in case of derailments. Do we not waste, then, a lot of metal in all those cases where we have, for example, deck bridges with ties resting on the top chord and where the posts are at least just as much protected against these strains as the chords? It also seems to me that by applying this formula, we make in a long span bridge with heavy posts a much more ample provision for these accidental stresses than we do in a short bridge with a very light post. I should think it more advisable to figure with one formula for posts and chords, but make the posts in through bridges strong enough to withstand a bending moment in case of an accident. This moment would naturally be the same in long and short spans, though it might be advisable to fix on a higher moment for the end posts, as these are more liable to get a square shock, while intermediate posts would probably get it under a flat angle.

I do not see that the danger of the top chords sideways buckling in pony lattice girders is so very great, if the girders are properly designed. These girders ought to have wide chords with double webs, and correspondingly wide posts with a solid web, well connected to the chord. It requires very little strain to prevent a member from buckling, and we can easily make the posts strong enough to do this work; they naturally will bend over when the floor deflects and tend to distort the chords; but I very much doubt that these additional strains will be more than the additional strains in the posts of through bridges from the same cause. For single track spans from 80 to 110 feet I prefer a lattice pony truss to a through bridge. The latter always has a more or less flimsy appearance, and has hardly sufficient lateral stiffness in its main members unless we throw in a great deal of extra metal. In reference to combining stresses, it is undoubtedly correct to allow higher permissible strains for the combination of dead and live load with wind and momentum. I do not think it right, however, to allow higher strains for the combination of dead and live loads with the centrifugal force corresponding to an average speed, as the horizontal centrifugal force is just as much of a regular load in our bridges as the vertical dead and live load.

By Palmer C. Ricketts, M. Am. Soc. C. E.

Mr. Waddell has brought out in a very interesting manner some of the disputed points in bridge design, and it seems to me advisable that every member of the Society who is particularly interested in this branch of the profession should at least express an opinion on the questions considered in his paper.

I have always thought that the method of wheel concentrations, as used in calculating the stresses in single system truss bridges, would sooner or later pass into disuse, not so much on account of the increased labor involved in the calculations, which I do not think is great, as because it would finally be realized that the accuracy attained by its use is more apparent than real. Who would venture to say that the stresses actually induced, by the varying loads of ordinary traffic in the members of any railroad bridge designed with typical engines, even closely approximating those in actual use, would be identical with those shown on the stress sheet of the original design; or that they would generally come within a considerable percentage of those given by the stress sheet?—and as a matter of fact no engineer is justified in specifying loads which do not considerably exceed those in general use on the road for which the bridge is designed. That is, he must assume a load which will make provision for unknown increments due to future traffic. The method looks and is what may be called elegant, but whether the metal is more properly placed by its use is entirely questionable.

I have considerable sympathy also for those who object to the use of an equivalent uniform load, namely, because there is no such thing. Mr. Waddell has made out a very good case for the average equivalent uniform load obtained from the bending moments due to typical engines and their following load, but it seems to me that the use of a uniform load made heavy enough to cover a certain probable future increase in car weights with uniform excesses taken large enough to cover a certain probable future increase in engine weights, is a more simple and all things considered more rational method of providing for the proper distribution of the metal in the trusses, than the use of an assumed typical engine or two followed by a uniform load, or than an assumed equivalent of this assumed load. In any case, as long as so little is known of the dynamic effect of the moving train on the various pieces of the structure, I believe that it is not scientific to split hairs on either the relative position or the magnitude of loads which are only assumed anyway, and which, in view of the future, never should be assumed to give the same stresses as those induced by existing traffic even when statically considered.

In specifying wind pressure for large spans, it is well to remember that observations so far made show that very great wind pressures occur only over very restricted areas; and that such great pressures are extremely unlikely to be found distributed over areas as large as the vertical projection of the longest spans now being built.

I am glad to see the opinion expressed that lattice bridges longer than 100 feet should be used. It was, perhaps, natural that the reaction from tubular and long lattice bridges should carry the advocates of pin bridges in the opposite direction to such an extent as to cause the writer of a well-known set of specifications in a former edition to require all through structures of more than 90 feet in span to be pin-connected. In a later edition he has raised this limit to 100 feet, and I think it should be still further raised, though, perhaps, not to the extent indicated by Mr. Waddell. For a single track, I think that all bridges over, say, 140 feet in span should be pin-connected; and for a double track, all over, say, 120 feet. Pin bridges may be preferable for somewhat shorter spans, and for longer ones, I think, they certainly are so, for well-known reasons—because the ratio of dead to live load becomes more considerable and the members larger, while in lattice bridges of longer spans the difficulty in making proper connections becomes greater and the loss of material becomes considerable.

The spindly, four-paneled, pin-connected through bridges 100 feet long, which have been turned out in the past even from the best shops, have not been admirable specimens of design; and though present practice has modified some of their defects, they are still not by any means the best that can be used. Of course there is ambiguity in the determination of the stresses in bridges of more than one system, and it is more rational, as far as the determination of these stresses is concerned, to use one system only; but since the best bridge is that one which carries a given load most safely and economically, it is most rational to use for any span that kind of a bridge which most nearly satisfies this definition; and as in all other engineering work, observation of existing structures may modify theoretical conclusions. Observation of well-designed and well-constructed lattice bridges 100 feet long has shown them to be stiffer and safer structures than pin bridges of the same length, and it has yet to be shown that the best designed bridges of this character cost more for maintenance, or need renewal sooner than pin bridges. Because lattice bridges as they used to be built, with webs connected by one leg, no angles on the lower sides of the top chord webs, etc., are not good bridges, it does not follow that those of the best present designers should not be used. The writer does not mean it to be inferred that he does not consider single systems advisable in most cases, but only that the use of multiple systems is excusable in certain cases.

As to the use of pony trusses, the increase in the length of plate girders, rendered commercially possible by advancements in mill and shop practice, will probably soon do away with them to a great extent.

There seems to be no question of the correctness of the present tendency toward riveted instead of hung floor beam connections, that is, when these connections are so made that both channels of the post act together or nearly together; and as giving greater rigidity, riveted, instead of adjustable lateral connections, seem generally preferable. So long as stringers are spaced so that the inside of the guard timbers are outside their webs, I can see no sufficient reason, as far as safety is concerned, for spreading them further apart; for the flaring of the guard timbers at the ends of the bridge should bring any train off the track inside these timbers, and the wheels will then be inside the stringers also. If the train is so far off the track that it cannot be brought inside the guards before it reaches the bridge or if it mounts the guards while it is on the bridge, an accident is almost sure to result, whatever the flooring may be. The floor system adopted by Mr. Waddell is certainly a safe one, but it seems to me to be unnecessarily expensive. As a matter of fact, with ordinary 6 x 8-inch guard timbers, flared at the ends of the bridge, notched 1 inch over closely spaced ties and bolted to them and to the stringers at frequent intervals by hook bolts, there seem to be few cases of derailment in which the train could not be safely guided over the bridge, that is, of those derailments which could be taken care of by any floor. Most engineers know of cases in which derailed trains have been kept between such guards on such a floor for great distances.

I do not doubt that the time will soon come when steel will wholly replace wrought iron, not only in bridge work, but in almost all structures and machines in which such iron is now used. It seems to me, though, that there are few engineers who would care at present to use this material only in bridges, in exactly the same way that wrought iron is used—with holes punched and not reamed in tension as well as compression members—and unless it is so used it cannot be said that it is practically as cheap as iron, for spans of ordinary lengths at least. But even though wrought iron should not be ruled out by the specifications, there hardly seems to be much doubt about the advisability of using steel properly throughout, even at an increased price.

I think Mr. Waddell's allowed unit stresses good ones for this material, and agree with him in believing that it is irrational to double the allowed live load unit stresses for the dead load. The theoretic deduction as to the effect of a suddenly applied load cannot, I believe, be properly applied in this way, as the application of a train to a bridge is not sudden in the sense above used, and the induced stress even in the floor system cannot be said to be due to a suddenly applied load.

By G. Bouscaren, M. Am. Soc. C. E.

LIVE LOAD.—In the light of past experience, the proper live load to be assumed in the computation of railway bridges is a matter well worth considering. The old practice was a uniform load of 1 ton per linear foot of single track; this, with the short panels commonly used then, gave very weak primary members and floor connections, even for the light engines and cars of the time. The breaking of floor beam hangers was of common occurrence in those days.

The substitution of a train diagram composed of one or two typical locomotives followed by a uniform load was an improvement on the old method. The writer introduced it, he believes, for the first time in the specification for bridges on the Cincinnati Southern Railway in 1874. The engines of the diagram were the heaviest which were expected to be used on the road at that time.

With the past now before us, it may be said that it was a mistake not to provide for the future by a heavier load; this necessity was not as evident then as now; besides, it has ever been a popular principle with a certain class of wise managers to "take care of the present and let the future take care of itself." The outcome of this policy has been the renewal of a large number of iron bridges, which had their life—supposed to be eternal—shortened to that of wooden structures, by the evolution of American locomotives and rolling stock; a great many more only owe their prolonged existence to a depleted condition of the company's treasury.

It seems to be a matter of common sense that the live load assumed in calculations should not be exceeded in its effect on the different members by any actual load ever likely to come upon the structure. In this respect the usual arrangement of two typical locomotives followed by a uniform train load is defective, inasmuch as it does not give the greatest stress in all cases. For instance, the chord stresses will be materially increased in long spans if the locomotives are supposed to be preceded as well as followed by the uniform load; again, in iron bridges, cantilever bridges and continuous girders, larger stresses will occur at certain points of the web and chords when the live load is supposed to be distributed in a discontinuous manner over the bridge. This condition is liable to occur, and does occur quite frequently, on bridges where trains follow each other closely, and when, from their position in proximity to a yard, switching has to be done over them. The arrangement and distribution of the load should therefore be prescribed as that giving the greatest result in each case.

The distinction between engines and train in the load diagram is not as important now as it was, for the reason that the train weight per linear foot has increased more rapidly than the engine weight per linear foot, the excess of the latter over the former having been reduced from 40 or 50 per cent. to 20 or 25 per cent. The fact remains, however, that the present form of load diagram is the most convenient to represent the intensity of the load desired, and it is not likely to be abandoned by railroad engineers except for a train of typical engines, which is being done in some specifications.

As regards the use of equivalent uniform loads for the purpose of computation, it is simply a matter of choice with engineers. The particular method of calculation employed is immaterial, provided it leads to correct results, and no reasonable man will object to the use of equivalent uniform loads or to graphical construction, if the stresses are accurately determined thereby. It is always well, however, to check one method of calculation by another; an exact coincidence of result is unnecessary, a variation of 2 or 3 per cent. is quite admissible, but it is advisable to keep on the safe side by adopting the larger figure in every case. Uniform loads are generally used in the computation on arch ribs to save labor, but the advantage to be gained in the case of ordinary trusses is much less. The writer must take exception to Mr. Waddell's remarks to the effect that the ordinary engine diagram cannot be used conveniently for finding bending moments in plate girders; he has used this method for many years. The weight and moment diagrams, such as given by Mr. Ward Baldwin in a recent paper read before the Society, having been once constructed, can be used very expeditiously to determine, not only the maximum moment at any point of a stringer, but the stress as well, and the maximum reaction on floor beams for any length of stringers. These diagrams, which need not be so elaborate as shown by Mr. Baldwin, can be readily drawn in a very short time, and their usage reduces very much the labor complained of.

The avoidance of the great variety of engine loads now being used in specifications is a great desideratum; a great number of them differ only slightly, but require, nevertheless, the construction of independent weight and moment diagrams, which is an unnecessary burden and annoyance. Five or six typical engine loads would cover the range of requirements for all classes of roads. The writer's criticism of the series of types proposed by Mr. Waddell is—1st. That it starts with too heavy engines for the lightest load, and ends with too light engines for the heaviest load. 2d. That all his engines are given the same length, whereas, as a rule, actual lengths increase with the weight. 3d. That his driving wheel-box is somewhat longer than obtains in actual practice. The addition of a heavy passenger engine to the ordinary load diagram is a good provision which should be retained in the specifications. In spite of the tendency to long panels, short ones will occur occasionally, when the greater weight on a single pair of drivers will be the ruling factor. The application of this wheel load as a check in special cases is certainly no great burden on the computer.

WIND PRESSURE.—American practice with regard to wind pressure was pretty clearly shown by C. Shaler Smith's paper on that subject and the discussion thereof published in the Transactions of the Society for 1881.

The practice is about the same now as it was then, viz., 30 pounds per square foot on the loaded structure, the pressure on the train being considered as a moving load; 50 pounds per square foot on the empty structure, the greatest result to rule in every case. No new facts have come to light since then warranting a decrease in these pressures; on the contrary, bridges continue to fall down from time to time in the track of tornadoes. The increased weights of trains and engines have increased the pressure of wind necessary to overturn them. If the pressure of 30 pounds on the loaded structure has not been increased to meet this altered condition, it has been, I suppose, on the ground that no train would be likely to venture on a bridge in such a hurricane; still it might be caught there, which would be a reason for assuming a heavier pressure than 30 pounds for small spans at least.

After all that has been said on the subject there seems to be no good reason for reducing the pressures. The fixed amount per linear foot given in certain specifications is based on the pressure of 30 pounds, and is understood to apply only to small spans. As the actual surface exposed to the wind is not proportional to the length of spans, and will vary quite materially with the design for the same span, the writer has always preferred to compute the surface for each case; it requires but little time to do so.

There is no longer any doubt that a pressure of 50 pounds and over is frequently reached by wind storms in this country. Shaler Smith, in his paper, gave several instances of well-observed facts to prove this, and no one would be disposed to question the results of his observations who has seen the effect of some tornadoes which have swept over different parts of the country within the last few years. The width of zone of greatest intensity in such storms is admitted to be small; but surely this is not a sufficient reason for omitting altogether the consideration of the effect of these great pressures on empty structures, especially when it is known that they are often accompanied by a lifting force of unknown power which tends to increase their effect on the stability of the structure. In the writer's opinion it is certainly risky to assume less than 50 pounds per square foot on an entire empty span, whatever may be its length. In France and England, where the intensity of the wind is not likely to be greater than it is here, the pressure assumed on empty structures is generally above 50 pounds. With regard to the effective areas for wind pressure, the writer's method of computing them concurs with Mr. Waddell's.

In the computation of wind stresses the principal points of difference seem to be: 1st. Whether the transmission of effects in the upper half of the truss should be considered as going through the top lateral bracing or through the vertical transverse bracing. 2d. Whether the bottom of end posts in through bridges should be considered as fixed or hinged laterally. The writer's practice is to consider the transmission to the abutments or piers as taking place exclusively through the top lateral system, this being the most direct course, and to consider the end posts as hinged at the bottom, there being always enough play on the pins to allow free elastic deflexions laterally. These assumptions are on the safe side.

As stated in the paper, the effects of the wind on the chords are often a disagreeable surprise to bidders who neglect to take it into account in the first place, on the assumption that with the larger working stress allowable for the wind, no addition to the sectional area will be required. For large spans the necessary increase of section may be very material. It is well also to test the effect of the lateral pressure of the wind on long and slim struts; the bending moment due to the wind may require an increase of sectional area or the remodeling of the section.

STYLES AND PROPORTION OF BRIDGES.—The writer agrees with Mr. Waddell, that for small spans which can be shipped whole riveted girders are preferable to pin-connected trusses; they contain more material, but this is more than compensated by their staunchness, and the fact that they can better stand neglect, a point which, unfortunately, should always be taken in consideration.

Pony trusses should not be condemned without reserve; there are cases where their adoption is dictated by circumstances and a proper regard for economy, as, for instance, where the crossings of several small streams occur on a stretch of level grade, with a small elevation of grade above high water which does not afford the necessary room for deck girders. Raising the grade for its entire length might be too costly; on the other hand, short approaches to each bridge, introducing several humps on the level stretch, would be very objectionable, especially on a road where fast trains are to run. Pony trusses are the best solution in such cases; they can always be made entirely safe by a liberal treatment of the top chord.

The Pratt and Whipple systems of web bracing, with vertical intermediate and inclined end posts and an inclination of diagonals approximating 45 degrees, are probably the best forms of trussing for economy and simplicity of connections with the floor system. In his later practice the writer has avoided the use of the Whipple form on account of the theoretical uncertainty of even distribution of strains between the two sets of web bracing, although he believes this objection to be more specious than real. Beyond 200 feet the Petit truss is advisable, to reduce the length of stringers and maintain the proper inclination of diagonals.

The writer agrees with Mr. Waddell in giving preferences to the strut over the ties in subdividing the panels; although it is done at the expense of more metal, the use of the strut avoids all ambiguity as to the distribution of the load and adds to the rigidity of the structure. The fact that one-half of the floor beams are suspended in the Petit truss is not an objection if they are properly connected to the chord.

Beyond 250 feet a polygonal shape of the top chord is advisable on the ground of economy. To better accomplish this object the angles should be suitably selected to maintain a continued increase in the stresses of the web members from the center to the ends of the span. Polygonal top chords when properly designed are, in the opinion of the writer, more pleasing to the eye than straight chords in long spans. The ordinary rule of 14 feet clearance between trusses will generally give a ratio between distance from center to center of trusses and length of spans greater than $\frac{1}{16}$; this ratio can safely be reduced to $\frac{1}{20}$ for long spans; beyond this the working stress per square inch in the top chord should be reduced in proportion to said ratio by the formula for compression members.

The proportion between the depth and the distance from center to center of trusses cannot be formulated by a fixed rule; the economy, stability and rigidity of the structure are the principal elements of the question, which should all be duly considered. The limit of 3 to 1 seems high enough; with a width equal to one-twentieth of the span, this would lead to a depth of truss equal to three-twentieths of the span, which is not generally exceeded for long spans.

The necessity of properly designed guard rails and rerailing devices is universally recognized, but the advantage of increasing the clearance from 14 to 16 feet on spans of moderate length is questionable. Such increase would add materially to the cost of the lateral and floor systems, and would not be likely to prevent the class of accidents against which guard rails and rerailing devices are ineffective, such as collisions, broken axles and broken tracks.

In deck spans it is very desirable, when practicable, to carry the masonry to the top chord, to secure greater stability and rigidity.

All adjustable parts in a bridge should be avoided, if possible, for the reasons that they seldom stay in adjustment, that they are consequently a source of expense in maintenance and that they are often overstrained by incompetent men. The writer has seen the end bars of the bottom chord in a 150-foot span buckled by the overstraining of the end lateral rods; he makes it a rule now to use riveted stiff diagonals in the bottom lateral system of through bridges and the top lateral system of deck bridges; he also avoids adjustable counter rods by making all the web members, where a reversion of stress is liable to occur, able to resist tension and compression.

The riveted connection of floor beams to posts is open to the objection of inducing tension in the upper rivets and a bending moment in the post. On the shore spans of the Ohio River Bridge and on the Kentucky River Bridge, on the Cincinnati Southern Railway, where this form of connection was adopted, the top rivets get loose and have to be renewed from time to time. This can be avoided by a top tension bolt of sufficient strength to resist the flange stress of the beam considered as fixed at the ends to be on the safe side; the bending moment induced from the beam should also be duly considered in proportioning the post. Unsupported tension rods or bars of great length are injurious to the rigidity of the structure and should be avoided. It is not always convenient to preserve a fixed proportion between the length of bars and their depth of section, and there seems to be no necessity for doing so if the fiber stress induced by the weight of long bars is taken into account in proportioning the bars; the best plan, however, is to support the bars properly.

The first requisite of a safe deck is to be impenetrable to a derailed train. The ties should be strong enough to resist individually the impact from the heaviest wheel load; they should be firmly fixed in position and spaced close enough to prevent bunching under the raking of the derailed wheels. The writer uses a 4-inch space between ties; every tie is locked laterally by the stringer web projecting 1 inch above the flange angles; this is better than dapping the ties on the stringers, it requires less labor and avoids the danger of splitting the ties at the shoulder; every tie is fastened to the outside timber guard by a five-eighths-inch lag screw and every third or fourth tie is bolted to the stringers. Lag screws are preferable to bolts, which will lose their nuts and drop off.

On the Cincinnati Southern Railway bridges the inside faces of the timber guards were all lined with 3 x 3-inch angles; these angles had to be taken off; they got loose in time by the effect of temperature, curving up and out of line at the ends, and becoming a source of danger instead of a safeguard. In addition to the outside timber guard, the writer uses an inside guard rail made of old or second-class rails laid with inside shoulder braces. Both guards are 7 inches from the head of the track rail, a sufficient space for wheels to run in without skewing. It is safer to use long ties with auxiliary side stringers, the main stringers being placed directly under the rails. Where this is not allowable on the ground of economy the main stringers are spaced from 6 to 8 feet, according to length of floor beams, and the ties proportioned accordingly with a minimum depth of 8 inches. When practicable the deck should be of hard timber. For the reasons given by Mr. Waddell, long leaf yellow pine is perhaps preferable to oak, but the objectionable features of oak are very much lessened if care is taken to lay every stick with the heart side down; in that position it will not split and check under the action of the sun, and will last much longer.

INTENSITY OF WORKING STRESSES.—There seems to exist without sufficient reason therefor a great diversity of opinion among American engineers with regard to the proper limits of working stresses.

The experiments made by Woehler and Spangenberg, under the auspices of the Prussian Government, and the Launhardt's formulas which have been deduced therefrom by a generalization extending beyond the scope of the experiments, seem to be responsible, in a large measure, for this state of things. We have apparently been too hasty in adopting these formulas without sufficient investigation. The engineers of England, France, Belgium, Holland and Prussia, who follow very closely what is being done by their neighbors, have, as a rule, left these formulas severely alone. All that can be claimed as legitimate conclusions from Woehler's experiments are the facts, heretofore suspected but not proven:

FIRST.—That an intensity of stress intermediate between the ultimate strength of the metal (as measured by a single application of load) and its limit of elasticity will always produce rupture, provided the number of applications is sufficiently great.

SECOND.—That within the limit of elasticity the metal will stand, without breaking or being injured in any way, an indefinite number of applications, whether the stress be always in the same direction or be alternately in tension and compression.

If the writer is correct in this statement, he is forced to the conclusion that Launhardt's formulas deduced from experiments on crippling stresses cannot apply by any scientific process of reasoning to elastic stresses, the only ones with which we are concerned. The single teaching of the German experiments is that the working stress should never exceed the elastic considers as excessive, it seems sufficient to say that this value is well within one-half of the limit of elasticity of the metal, and therefore entirely safe; considering that the ratio $\frac{l}{r}$ being supposed to be less than 50, the flexion formula for posts does not apply. It is also well to bear in mind, in comparing values of working stresses of different specifications, that where they include the effect of impact reduced to static value they must necessarily be greater than where they do not.

COMBINED STRESSES.—For wind stresses or a combination of wind and other stresses, the writer specifies a maximum working stress of 25 per cent. in excess of the working stresses without wind, which is equivalent to five-eighths instead of one-half of the elastic limit. This is considered allowable on account of the rare occurrence of winds of such intensity as are assumed in the calculation. Formerly this working stress was taken as three-fourths of the elastic limit; it has been reduced by the writer to five-eighths, in consideration of the rhythmic action of the wind, which causes a certain amount of impact and considerable vibration.

The writer concurs with Mr. Waddell's method of treatment of the end posts in through bridges, excepting as to the maximum value of the working stress under the combined effect of the wind and other loads, which he thinks should not exceed five-eighths of the elastic limit as explained above. It seems inconsistent to admit 20,000 and 24,000 pounds for the combined action of the wind, when the working stress without wind is limited to 9,000 pounds. I hope Mr. Waddell will give us his reason for doing so.

Referring to the subject of plate girders, the web, if made thick enough to give sufficient bearing for the flange rivets, will generally with proper stiffening be found to be of ample strength. The only point likely to be weak is at the ends, especially if the height there has been reduced for a shallow seat; it may be necessary to reinforce the web with thickening plates in addition to the stiffeners. Deep plate girders with thin webs, properly stiffened, act more like trusses than solid beams; although the web plate participates to a small extent in resisting the bendings, it is safer to assume that the whole duty falls on the flanges. The web is generally spliced with regard to shearing only; if it is relied upon to resist any part of the bending moment, it should be spliced accordingly, and wider plates and a greater number of rivets will be required than are generally used. When flange plates have to be used, it is important to have as much metal as practicable in the flange angles, as they are certainly strained more than the plates, owing to the eccentricity of the web attachment and the unequal distribution of stresses.

GENERAL DETAILS OF CONSTRUCTION.—In the writer's opinion, the details and the general design are of equal importance, because all the advantages of a good design may be lost through faulty details. Greater progress has been made perhaps in the design of details than in any other branch of the art. If we are yet too far from perfection to rest on fixed standards, even for ordinary spans, we should, for the purpose of criticising our own work, keep in mind the principal characteristics of good details, viz.: 1st. An arrangement such as will secure the independent action of the several parts, as intended in the general design, and prevent one class of members from sharing in the duties of another, or doing work which it was not designed to do. 2d. The avoidance, as far as practicable, of secondary stresses, such as bending moments in tension and compression members, which are liable to be overlooked, causing an excess of working stress in these members, or, if properly considered, leading to an expensive increase of sections. 3d. A form and disposition of parts that will insure as nearly as possible a uniform distribution of stress through the sections, which requires a close coincidence of the resultant lines of stresses with the centers of gravity of sections. 4th. If the above conditions cannot be entirely fulfilled, the details should be such at least as to permit a correct analysis, that will leave no ambiguity as to the distribution of stresses. 5th. Tension in rivets should be entirely prohibited, and the position of field rivets should be such as to give ample room for good work.

The 1st and 5th conditions should prohibit the riveting of both ends of stringers to floor beams, excepting for very short spans. It is best to have a riveted connection at one end only of each stringer, with a slip joint at the other. This is in no way prejudicial to the rigidity of the structure, which is entirely secured by the horizontal lateral system. A continuous length of 150 feet of rigidly connected stringers is too great; the elastic elongation of the chord for that length due to the live load would be in the neighborhood of one-third inch, which is sufficient to create a very objectionable tension in the riveted connections and undue stresses in the stringers and floor beams.

The writer agrees with Mr. Waddell in condemning beam hangers, with screw ends, but does not see any objection to the suspended floor beam if properly connected otherwise with the chord to transmit the wind stress; it secures a better distribution of the panel load at the panel point than a riveted side connection of the beam with the post. In double track bridges the riveted connections to posts are open to the further objection of unduly straining the rivets and causing undue bending moments in beams and posts, owing to the unequal deflexion of the two trusses when one track only is loaded; this is probably the reason for prescribing suspended floor beams in double track bridges on the Atchison, Topeka and Santa Fe road.

The writer would not dispense with the reaming of rivet holes in mild steel, and believes in reaming iron as well when a full duty is expected from the rivets. Reaming is the only sure way of securing an exact coincidence of rivet holes, which is an essential condition for good work. Another reason for not dispensing with reaming in steel plates is the well-known fact that hard spots are of frequent occurrence in the softest steel.

The length of stay-plates at the ends of compression members is a very important item; their function is to distribute the stress uniformly through the section; and they should be long enough and have a sufficient number of rivets to do so in the most unfavorable case that can and does happen, where the bearing is altogether on one side of the post. The influence of the end plate on the carrying capacity of built posts was clearly illustrated in several instances of column tests made by the writer.

The latticing between posts should also be made stronger and more substantial than is generally done; it should be proportioned to the weight of the post, and the lattice bars made stiff enough to preserve their shape in handling members before erection. Bent lattice bars are a noticeable feature in nearly every bridge through the country; this is proof enough that they are generally made too weak.

By H. H. Filley, M. Am. Soc. C. E.

Although bridge designing has been one of the leading subjects of investigation among the engineers of this country for a generation past, the subject is by no means worn threadbare, and from this résumé of disputed points by Mr. Waddell, the conviction is strengthened that enough still remains to keep the subject well to the front for a long time yet. There is one fact which the author states concerning live loads in bridge calculations that should not be lost sight of in considering different methods of calculation, viz., "It must be acknowledged, therefore, that all assumed loads for computing stresses in bridges are merely typical." The engine diagram nicely drawn to scale, with its careful spacing, its large driving wheels and its small leading and tender wheels, looks so rational and real that it is little wonder that we find ourselves looking upon it as showing the exact loads to be taken care of; but it is, in fact, only an approximation. Probably the nearest approximation in use, and yet not near enough to warrant the condemning of a simpler substitute on account of discrepancies of 2 or 3 per cent. in the results.

I am not disposed to the extreme views entertained by some, that the use of engine concentrations has been an unmixed evil in this country, but am strongly of the opinion that the average railroad bridge built during the past ten years is better proportioned on account of it. The results obtained from its use seem to give satisfaction, and are what the advocates of uniform loads are trying to obtain, and they are willing to accept them as the standard for checking their shorter methods. For that purpose, I believe this method should still be retained; but for the every-day work of the engineer in dealing with ordinary girders and trusses it seems analogous to the taking of ground readings to the nearest hundredth of a foot in ordinary earthwork cross-sectioning. The result is a vast amount of office work with quantities carried out to three or four places of decimals, but actually no nearer the true volume than could have been obtained from half the work. If to the expert, who from continuous practice is enabled to apply numerous short-cut rules in his computations, the engine concentration method is a "burden grievous to be borne," what is it relatively to the railway engineer, who, in addition to his other manifold duties, is called upon to check the calculations of half a dozen bridge companies every time he is allowed to replace an old wooden with a new metal bridge—this permission usually occurring at such rare intervals that at each "letting" he finds himself as rusty on the subject as he was at the former. The results which Mr. Waddell has obtained for truss spans are especially gratifying. If the variation is found to be no greater with different panel lengths, ranging from 20 to 30 feet, it would seem amply accurate for ordinary use.

Much routine labor may also be saved to both the railroad and bridge engineer by the more extensive adoption of standards. There are, of course. cases on every railway system of any considerable extent where the most complete set of standards must, from local considerations, be discarded, but such cases are not numerous. In preparing such standards no attempt should be made to include skew and such other exceptional structures as bridges for spanning large navigable rivers, but all ordinary cases may be fully covered. The length should vary by not more than 5 or 6 feet up to clear spans of 30 or 40 feet; by not more than 10 or 12 feet to spans of 150 or 160 feet, and for longer spans by not more than 15 to 20 feet. Some engineers have adopted standards, good so far as they go, but varying by so great a length that in too many cases they lead either to useless extravagance or dangerous economy. With spans varying by 30 feet, there is, perhaps, as much danger of making, in any particular location, the opening 15 feet too short as 15 feet too long, depending, of course, somewhat on how prominently the economic needs of the company are impressed upon the mind of the engineer. The proposed increase of clear roadway for through bridges would doubtless give additional security, and may well be carefully considered by engineers in preparing standards. Where piers or abutments are high, the increased roadway, of course, adds quite an item to the cost of substructure.

Probably the next consideration in order of importance, after determining lengths of spans and widths of roadway, is depth of floor system and number and spacing of track stringers. These dimensions should all be fixed before proceeding to design standards for substructures. There should also be standard designs for the flanges of stringers, to facilitate the sizing and framing of cross-ties in the shop. This is especially desirable where timber is to be creosoted. Where roads pass through thickly settled districts, it will be well to design a special floor system of the least practicable depth for overhead crossings. With our present knowledge and experience, the standardizing of bridge superstructure need not stop with the four or five sets of dimensions already mentioned. Before commencing the permanent bridging of a line, the chief engineer, together with an expert, if necessary, should take up the subject systematically and prepare complete designs for standard spans. Avoid such unusual shapes and details as cannot readily be produced at any well-equipped bridge shop.

In any such set of standards there will, of course, be defects, and it will be found in time that the designs are behind the times and a revision is necessary. In the meantime the engineer will, however, have gained an experience from the use of several bridges of a kind under identical conditions of service which will enable him to determine whether the defects developed are faults of material, workmanship, or design with much more certainty than he possibly could if each structure was made from a separate design. He would also avoid the unsatisfactory task of wading through a half dozen or more sets of plans and checking as many sets of calculations for every bridge contract let (usually in a great hurry, as, when an iron bridge is decided upon, it is wanted right away), and finally adopting, on account of price, a bridge less desirable than he intended, because some bridge company had taken advantage of some loophole in the specifications and "skimped" in places without actually violating their requirements. That our American method of bridge letting, which has stimulated competition in designing, as well as workmanship and prices, has been a potent factor in bringing the American railway bridge to its present state of excellence, is doubtless true; but it is also equally evident that in very many cases this competition in design has been carried too far. There seems now to be sufficient uniformity in the designing of ordinary spans to justify the calling of a halt in this branch of the competition. Let the railroad companies spend some of the money which such designing costs in more liberal details and better floor systems.

A rational formula for the "intensities of working stresses," it seems to me, should begin with strictly static loads. Starting from this basis, the effect of impact and vibration caused by different kinds of variable or moving loads may be provided for, either by additions to calculated stresses, or by subtractions from dead load intensities. By comparing several sets of specifications in common use, I find the ordinary intensities, in tension members, of railway bridges, to be, for "eyebars" about 54 to 64 per cent., and for "plates and shapes" about 46 to 56 per cent. of the specified minimum elastic limit of the metal. By comparing specifications for iron work only, the deviations of practice are found to be somewhat less; with long compression members, of course, practice differs by a much greater amount, yet very rarely to the extent shown by the author in comparing Mr. Cooper's with Mr. Bouscaren's specifications, in the rather exceptional case of a post which carries no dead load. But even in that case, as I read Mr. Bouscaren's specification (1890 Edition), the actual working intensity would be reduced (from the 12,000 pounds per square inch as stated) by his addition to calculated live load stresses, to provide for impact and vibration, viz.:

"For web members of trusses $50\left(1-\frac{d}{250}\right)$ per cent., where $d=$ distance of member from center of truss." If, therefore, the post under consideration is at the third panel point of a 250-foot span with 25-foot panels, or 50 feet from the center of the truss, the added allowance is 40 per cent. of the live load stress and the actual intensity becomes $12{,}000 \div 1.4 = 8{,}571$ pounds per square inch, or about 43 per cent., instead of 100 per cent., over that obtained by Mr. Cooper's specifications—still, however, quite a serious discrepancy. We can hardly hope that all differences of opinion concerning "intensities of working stresses" will be reconciled in the near future; at least, till there is more uniformity in the quantity of metal used as well as workmanship in construction, followed by a systematic series of tests on full size members to establish a safe mean for all desirable lengths and shapes. But if all bridge engineers could agree to begin the solution of the problem at the same end, and consider the strains from each kind of loading separately throughout, as Mr. Cooper is now doing in truss members, it seems more than probable that many of the present differences, which are often more the result of individual taste in the use of formulas than of evidence obtained from independent investigations or experience, would gradually disappear.

If any part of a bridge must be skimped, it certainly should not be the floor system, and this should apply to ties and guard rails as well as the stringers and cross-beams. The author's practice of bolting down through the stringer flanges instead of using hook bolts is good; not that the hook bolts are inefficient, but one of the important features of a floor should be the absence of bolt ends, nuts and other projections which would catch anything sliding over it, as a brake beam or broken-down truck or car; therefore the bolt should pass down through the flange, with nut on the lower end, while the head and upper washer should be countersunk into the tie or guard rail whenever the stringer spacing will permit. The bolting of every tie to the stringer seems unnecessary, especially with stringers 8 feet apart or more. The dapping of guard rails 2 inches over ties with only 5-inch spaces between daps is objectionable, although the 2-inch projection, acting as a separating block, gets a better hold on the tie than a less depth would; but it is more likely to split off and be lost entirely. Probably the surest way to prevent the bunching of ties on a bridge is by means of separating blocks securely fastened between the ties. Where the stringer spacing is wide, as on long deck girder bridges and viaducts, requiring a tie of considerably more depth than breadth, very satisfactory results have been obtained by uniting them in pairs by means of a bolt and separating block at each end, with separating blocks also between the pairs.

Oak timber is more apt to warp and check in seasoning than pine. These defects can, to a great extent, be obviated by a little attention to the felling of trees at the proper time and protecting the timber from sun and wind while seasoning. Oak ties should be nearly square in section up to 9 or 10 inches, as the timber warps less than when one dimension is much greater than the other. Oak holds a track spike better than pine, which is a desirable quality, for, besides the danger of the track spreading when spikes get loose, water follows them into the wood and decay begins. I do not understand that pine is exempt from dry rot; at least some kinds of mountain pine are so affected.

If rerailing devices and collision piles are used, they should be placed so far away that whatever of good or evil they do to a derailed car may be fully accomplished before the car reaches the bridge. Neither the number nor efficiency of guard rails should be reduced on account of such devices, for it sometimes happens that a truck is so slewed that it will not keep the track for any distance, even if effectually replaced by such means.

Bridge ties should be ample in dimensions and closely spaced, with at least inside and outside guard rails made smooth and continuous the full length of the structure—for the same reason that bolt ends, nuts, etc., should not be allowed to project above them. When ties are close spread, 12 or more feet in length, of suitable, well seasoned or chemically prepared timber, they aggregate a considerable item of expense, and their preservation becomes a subject worth careful consideration. Bolt and spike holes are doors for the admission of moisture and their number should be reduced to a minimum. The cuts and bruises from the flanges of a single pair of wheels off the track may reduce the life of a set of ties by one-half. This fact, together with the desirability of reducing the shocks produced by derailed wheels, has led to the consideration of this proposed plan (Plate XXI), which is, for the most part, a combination of several well-tried features picked up from the practice of different railways. The separating blocks of cast-iron for 4-inch clear spacing will weigh about 7 pounds each, and may be secured to each tie with a wood screw, or in pairs to each alternate tie, with a machine bolt. If ties are to be creosoted these holes may be bored before treatment. Where separating blocks are used and stringer spacing will permit, the holding down bolts may merely pass between the ties, engaging only the guard rail and stringer flange.

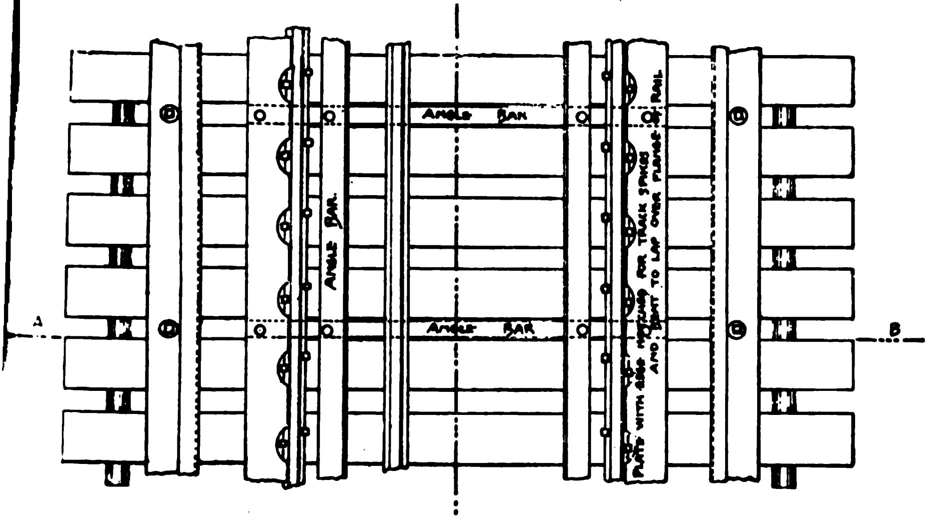
The turning of the horizontal edge of the angle iron used for the inside guard rail toward the rail, providing a smooth path for the flange of a derailed wheel, is not new; but the addition of a plate for the same purpose outside the rail and riveting both to angle-iron crossbars instead of bolting or spiking to the ties, are only the propositions for the consideration of those who may be interested in the improvement of bridge floors. If the company can afford old or light rails for additional inside guards, as shown on the left half of the plan, the security will be increased. Longitudinal planks covering the ends of the ties may also be of service.

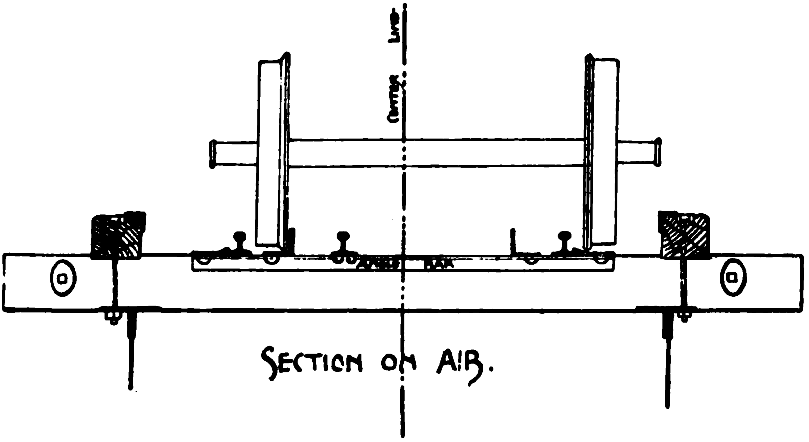
By John Sterling Deans, M. Am. Soc. C. E.

The paper recently presented to the Society by Mr. J. A. L. Waddell embraces subjects of the greatest interest in an important branch of engineering and as such should be thoroughly discussed, as requested by the author. The first point in the paper on which there is certainly great difference of opinion is in fixing the limit at which plate girder construction shall be used, at 100 feet. In the opinion of the writer, this limit is much too great and it is not a wise expenditure of money to pay for the extra cost of construction in spans of over 75 feet. Above this length the chords and diagonals of a well-designed lattice girder are necessarily of such a size as to admit of a satisfactory arrangement of rivet spacing at important connections, and also to make it possible to have the centers of gravity of the various members intersect at one point, so that the question of secondary stresses is reduced to one of little practical importance. An engineer with the latest improved system of power riveting at his command does not seem warranted in adopting plate girder construction of over 75 feet lengths. This extra expense is not one simply of extra metal, but of extra shop cost, handling and erection in the field. Again, in a lattice girder internal forces act along well-defined lines, and in this respect it more nearly approaches the perfect "American" pin-connected truss and differs materially from the plate girder, in which, as Mr. Waddell suggests, the exact manner of stress distribution is an open question. The lattice girder design can be economically and satisfactorily used up to spans of 135 feet; beyond this the sections become unwieldy for riveted connections and the pin style of truss should be used. At this day, with so many numerous examples about him, no engineer should be upheld in using anything but a single intersection main web system for the longest and heaviest truss spans.

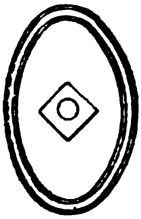
LIVE LOADS.—Under this heading, Mr. Waddell strongly advocates the adoption of standard uniform live loads, as against wheel concentrations; not that it is the more exact method, but in order to relieve the burden of the bridge computer. The writer is well aware of the character of such computations and of the really enormous amount of unnecessary work put on the bridge engineer, but thinks it is not caused, as Mr. Waddell intimates, by simply being called upon to use wheel concentrations in determining the stresses in various members, but by the innumerable kinds of loading, differing by an inch or two in wheel spacing and by a few pounds in weight on axles. That computations by wheel concentrations for a fixed load give the more exact result is not disputed, and it is certainly the manner in which loading is applied to a railway structure. It would seem to be more logical to adopt certain standard engine and train loads, and wheel spacing.

PLATE XXI.
TRANS. AM. SOC. CIVIL ENGRS.
VOL. XXVI, No. 522.
FILLEY ON RAILWAY BRIDGE DESIGNS.

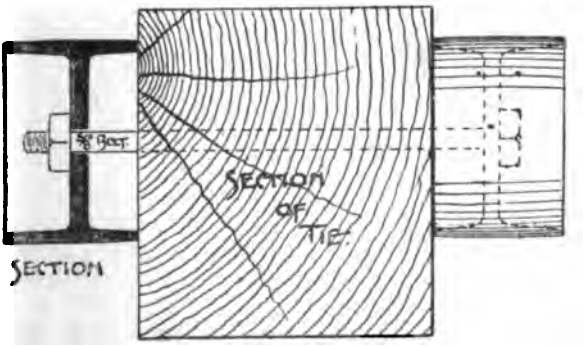




SECTION ON A-B.



PLAN



SECTION

DETAIL OF SEPARATING BLOCK.

By adopting a heavy and light type for the "Consolidation," "Mogul," and "Passenger" engines, and light and heavy train loads, all cases would be covered. With these two types settled upon and moment tables figured, the computer would soon be familiar with the loading which would give maximum results without trial, and it is a question whether it would not be the easier method, as it is certainly the better one to present to the average railroad officer. The latter would always question the propriety of using a uniform load, even though it might really closely approximate to an equivalent load, when he is aware that his bridge is subjected to the action of loads placed on it through axles and wheels. The writer believes that much more can be said against the ridiculous variety of types than against the method of computing stresses; he also believes that the great number of specifications which every railroad consulting engineer and inspection bureau seem to think it is absolutely essential should be used in designing their particular structures are the cause of much the greater part of the bridge engineer's work. No one not actually engaged in the designing and constructing of bridges has any conception of the mental labor involved nor the wearing effect of being compelled to work with these myriad specifications, differing often in really minor particulars; but these differences must not be overlooked, as they are each and all considered of vital importance by the author of the specifications. As a sample of these differences, a prominent railroad company calls for its steel eyebars to fill the following specifications:

Ultimate strength at least 56,000 pounds per square inch.
Elastic limit at least 33,000 pounds per square inch.
Minimum stretch of 10 per cent.

While another equally prominent company believes it is essential in order to secure first-class work to have its eyebars, having precisely the same duty to perform as those first mentioned, manufactured according to the following specifications:

Ultimate strength at least 60,000 pounds per square inch.
Elastic limit at least 30,000 pounds per square inch.
Minimum stretch of 15 per cent.

This is only one instance out of hundreds of the differences met with, and in fact is hardly a fair sample in order to make my point, for in such an important member as an eyebar there may be some excuse for great difference of opinion as to the best specifications and best mode of manufacture to follow. There are many cases known in which there appears to be not the slightest reason or excuse for differing from the regularly accepted practice. The parties or society that are instrumental in securing a standard bridge specification, or say two or three standards (as it would probably be well to provide for first, second or even third class construction and loads), would indeed be entitled to the gratitude of not only the bridge engineers of the country, but that sorely burdened class, the bridge constructors. It is next to impossible for these constructors to so arrange their shop practice and mill processes as to meet the various whims of all authors of specifications. It would seem as if this matter of a standard specification could be settled upon much easier than a standard uniform loading, and in fact, if specifications continue to be added to the present long list, the question must be met. As long as engines and cars are used to load structures, it will always be more rational to use typical engines and cars in designing them, and in the opinion of the writer we must look to the "Standard Specification" to relieve the sorely tried computer in whose interest Mr. Waddell has taken up the subject.

By Frederick H. Smith, M. Am. Soc. C. E.

In discussion of Mr. Waddell's timely paper, I would say that his remarks on the flimsiness of web systems resulting from excessive curvature of top chords recalls the controversy on this subject which raged in the early fifties. The builders of arched or bowstring bridges thought the world could get along with spider-web systems in bridges; the Howe truss men admitted that arches had their uses occasionally, but only as auxiliaries to trusses with heavy web systems, and McCallum combined the two plans by mounting an arched top chord on end arched braces, and lightened up his web system about proportionally. In 1852 a committee of engineers examined and reported on a McCallum bridge of 200 feet span over the Susquehanna River at Lanesboro, Pa., and in 1852-53 much of our engineering class-work at Pittsburgh was devoted to the discussion of this subject. In the fulness of our wisdom we decided that McCallum's combination of the two plans was worthy of our valuable commendation, but that he was not the first to build bridges embodying such combination; as we measured, illustrated, computed and discussed several small bridges in Allegheny County which had laminated curved top chords, vertical end posts, and variously inclined braces and rods, all reported by the neighbors to have been built by "Jim Finley," the man who first built iron suspension bridges in this country.

Some of the Howe truss men were so impressed by McCallum's business success (if not by his arguments) that they began arching their top chords, and a notable example of this practice was the Rock Island Bridge over the Mississippi River, which was removed when the present iron bridge was built by the late Baltimore Bridge Company in 1871-72. In the Rock Island Howe truss the web systems were as heavy as they would have been had the chords been parallel, and this is also the case in the curved top-chord bridge built in 1867-69 over the Missouri River at Kansas City, by President Chanute. The practical aspects of such curvature were carefully looked into in 1869-70 by the late C. Shaler Smith, M. Am. Soc. C. E., and myself in the Western office of the Baltimore Bridge Company, in connection with plans for a proposed tripartite bridge at Pittsburgh; and we found that a double intersection truss with radial posts and parabolic top chord required theoretically the least material. The attenuated web system, however, seemed to us to need the addition of about as much gratuitous metal as would wipe out this advantage, and as the shop and erection costs were excessive and the raking posts necessitated a suspended floor system, we dropped the subject in a business way, although I patented the radial posts as being the only feature that had not been anticipated by the Jim Finley and other curved-top bridges. The radial posts, by the way, had been first used by me in designs for a canal bridge to be manufactured by the Tredegar Works in Richmond, for Shaler and Fred. Smith, and this bridge, together with three 100-foot spans of Fink truss, which we had in hand for Chief Engineer H. D. Whitcomb, M. Am. Soc. C. E., for Jackson River, Virginia Central Railroad, were stopped by the outbreak of war in 1861.

In the matter of suspended floor systems, I note that some men who advocate this practice for modern beam trusses have omitted the "saving clause," so to speak, which was used by the builders of the old suspension trusses and the earlier beam trusses, viz., the use of a compensating suspension link and of longitudinal strut-ties between the ends of the floor beams, all so fixed that the lateral vibration was carried directly to the masonry without affecting the truss, and the truss could expand without affecting the floor system. In the absence of compensating suspension links, a suspended floor system, if bolted up tightly against the bottoms of the posts, will develop sooner or later some openings between the ends of stringers, and such openings had best be included in the design, as Mr. Waddell states. This is equally true when the floor beams are riveted in between the posts, either above or below the chords, unless indeed they should be on the neutral line of the truss; but trouble from such openings between stringers need not be looked for except in very long spans.

The north span, 255 feet long, in the Susquehanna Bridge of the P. W. & B. R. R., at Havre de Grace, designed and built in 1873-74 by the late Baltimore Bridge Co. (the shop-work being the first output of the Edgemoor Iron Co.), has floor beams riveted or bolted in between the posts above the chords, with stringers between the floor beams fished to each other over the beams, and resting on and bolted to end floor beams which ride on the end post shoes. This north span flattened its rollers somewhat, but the remaining eleven spans of this bridge built subsequently with the same floor details by the Baltimore Bridge Company and the Phoenix Bridge Company rolled freely, and I have never seen or heard of any serious distortion or other trouble arising from differences of expansion or contraction between the floor system and the chords. These stringers, however, are bolted (not riveted) together, the purpose being to allow for expansion at each joint. I have always used the above-described end floor beams riding on the end shoe, and fully agree with Mr. Waddell that it is very necessary. When the conditions are such that a suspended floor beam is necessary, I rivet it to extensions of the posts below the chords and rest the stringers on sliding shoes on the wall, and attach them and the lateral rods to struts which move with the end shoes, and thus keep everything drawn taut.

Mr. Waddell is undoubtedly right in advocating long panels and single intersections, and in subdividing these panels in long spans, but I am not at all convinced that by carrying the sub-panel load to the rear, or by any other device, he can effectually support his top chord with a sub-post at mid-panel. There have been removed and replaced this year several spans of what we called the "sub-truss Quadrangular" bridge, built by us in 1868-69, on the old Cincinnati and Baltimore (now B. & O. S. W.) Railroad. These spans were built to carry such wheel loads as iron rails would carry, and although they had recently been crowded beyond double duty, they never let go. The sub-truss eyebars ran fore and aft to the heads of the main posts, and we had to use full panel lengths in figuring top chords in overgrade spans, as we found that the sub-posts slacked away from the top chords under loading, just as in Fink trusses. The sub-truss does its work independently of the main truss, and puts a local and secondary girder strain on the top chord if the sub-post is attached thereto. While on the subject of top chords, I wish to express my satisfaction that so many specialists are now using chord joints in which the joint line cuts the pin center and the sections are held together by the passage of the pin through inside and outside overlapping plates with no field riveting. When I first used this joint in 1878, in New River Bridge, A. M. & O. R. R. (now Norfolk and Western), it was irreverently described as a moderately good "Highway" bridge joint, but it has made its way, and is now in very general use.

Mr. Waddell's position on the matter of using equivalent uniform live loads is well stated and argued by him, and I, for one, will be very glad to welcome his proposed contribution of tables therefor to the Society; but I hope he will include approximate percentages of error on the safety or the danger side of the line, and also some modifications in engine loads to cover the case of the decapods. The rule for finding floor beam concentrations by using in one panel length the equivalent uniform load per foot for a span of two panel lengths, the discovery and announcement of which is made by Mr. Waddell on his pages 266-7, has long been in use in my office, and was fully explained some years ago by Mr. Edwin Thacher in a paper to a Western Engineering Society in connection with his very valuable tables of equivalent distributed loads published in the Keystone Bridge Company's specification of 1887.

Mr. Waddell's proposition for us all to join in abolishing such superfluities as the second powers of lengths and radii, is one that I would very much like to see carried out if he will suggest a substitute which will change the method without materially changing the results. A good many computers have attacked this problem in the hope of lightening their own and others' labors, but no consensus has been reached, and there are yet at work some men (engineers, too) who, after proportioning by squares of radii, do not sleep well until they have again gone over their work in terms of diameters. Possibly their brain matter has crystallized.

In the matter of intensity of working stresses constituting Mr. Waddell's Group "D," I offer some suggestions in the way of items from a specification upon which I have just received tenders for about 1,600 tons of riveted lattice girders and columns, and a couple of pin-connected spans for the North Street Viaduct in Baltimore. Under the combined live and dead loads, working strains per square inch in tension in steel and iron members having net sections of 1 square inch or less, shall not exceed 34 per cent. in the case of riveted members, nor 37 per cent. in the case of eyebars of the herein prescribed elasticity of the material of which the member is made; and this percentage shall be reduced by one-tenth of 1 per cent. of the elasticity for each additional square inch of net section in built members, or in eyebars taken singly.

Working strains per square inch in compression in steel and iron shall not exceed 32 per cent. of the herein prescribed elasticity of the material of which the member is made, for sections of 1 square inch or less, and this percentage may be increased by one-tenth of 1 per cent. of the elasticity for each additional square inch of gross section in the member, the strains thus determined to be reduced by division by

$$1 + \frac{L^2}{(18,000\ R^2)};\ \text{by}\ 1 + \frac{L^2}{(24,000\ R^2)};\ \text{or by}\ 1 + \frac{L^2}{(30,000\ R^2)}$$ for members

with two pin ends, or one pin and one flat end, or two flat ends respectively. This percentage of decrease in allowed tension per inch, as the sections increase, is a recognition of the well-known fact, that as rolled metal increases in section and especially in thickness, it does not get so much mechanical work put into it by the rolling (measured per pound of product), and full size tests show very generally that its actual tensile strength decreases about proportionally. Shearing strains in field rivets of 20 per cent. and elsewhere of 30 per cent., bearing strains of 50 per cent. and bending strains of 50 per cent. respectively of the elasticity. In tension members composed of plates and shapes riveted together, the local stresses produced by driving rivets one at a time close to each other, and the uncertainties about filling the holes of interior plates when long rivets are used, especially in splicing heavy sections in the field, combine to reduce the certainties in the case of large riveted members far below the certainties in the case of eyebar members, which is my reason for taking eyebars singly when decreasing percentages.

It will be contended that there really should be no decrease in allowed working strains in tensions, on the ground that the larger the sections the longer the span, and therefore the less frequency in the application of the full load; but this was a good argument before modern railway practice confined freight traffic to full cars and long trains. Another argument against the decrease of working strains in tension as the sections increase is, that as the sections increase the proportion of dead load to total load also increases; but I submit that when the span is loaded, it is loaded, and the combined live and dead loads are working together (with some suspicion of impact from the acquired momentum or drop of the dead load also), and the main system should at that moment have metal enough in it to do the work. The formula for proportioning by minimum and maximum stresses needs further examination, and I hope Mr. Waddell will persuade himself and others to put through his proposed series of experiments. I will help him.

The percentage of increase in allowed compression per inch as the sections increase is in recognition of the fact that compression (instead of pulling things apart, as tension does) presses things together, and of the further fact of the greater resistance to flexure and shock as the metal thickens and sections increase. The larger sections are thus in every way more reliable than small ones, and can do proportionally more work and with greater safety. It is but fair that after specifying working strains per square inch based upon percentage of the prescribed elastic limit, I should also submit some of the items governing quality of the materials upon which I impose these stresses. I specify, among other things, that all iron shall have an elastic limit of 25,000 pounds per square inch; that standard specimens cut from plates, bars or shapes of one square inch section shall show an ultimate strength of 50,000 pounds and a stretch of 15 per cent. in 8 inches, and for each additional square inch in the bar, the specimen cut from it may show a reduction of 150 pounds per square inch in ultimate, and of two-tenths of 1 per cent. in the stretch. Full size

plates, bars or shapes of one square inch section shall show 50,000 pounds ultimate, and 12 per cent. stretch in 10 feet, and for each additional square inch of sectional area they may show a reduction of 200 pounds per inch in ultimate and of four-tenths of 1 per cent. in the stretch. Steel for rivets must show an ultimate between 53,000 and 57,000, an elastic limit of 28,000, all in pounds per square inch of full size rivet bar; a stretch of 25 per cent. in 8 inches and reduction of 50 per cent. Standard specimens cut from full size plates, bars or shapes intended for riveted work, and having a section of 1 square inch or less, shall show an ultimate between 55,000 and 62,000, an elasticity of 30,000, all in pounds per square inch, a stretch of 22 per cent. in 8 inches and reduction of 44 per cent.; for each additional square inch in section of plate, bar or shape the specimen cut from it may show a reduction of 100 pounds per inch in ultimate and of one-tenth of 1 per cent. in stretch, and this steel may be punched without reaming and be sheared without planing.

Specimens cut from steel for eyebars, rods, pins or rollers having a sectional area of 1 square inch or less, shall show an ultimate between 60,000 and 68,000, an elasticity of 33,000, all in pounds per square inch, a stretch of 20 per cent. in 8 inches and a reduction of 40 per cent.; and for each additional square inch of original bar the specimen cut from it may show a reduction of 100 pounds per square inch in ultimate and of one-tenth of 1 per cent. in stretch. Full size eyebars of this steel of a sectional area of 1 square inch shall show an ultimate between 60,000 and 68,000, an elasticity of 33,000, all in pounds per square inch; a stretch of 16 per cent. in 10 feet, and a reduction of 35 per cent.; and for each additional square inch of section they may show a reduction in ultimate of 150 pounds per square inch, of two-tenths of 1 per cent. in the stretch, and of four-tenths of 1 per cent. in reduction of area. Annealing, reaming and planing are prescribed for this steel.

It will be noted that there is no call for a specimen to be rolled down and tested for quality of steel in each melt, and I prefer that specimens for testing (except for rivet steel) shall be cut out of a full size bar, as this gives a test of the actual mill work as well as of the quality of the steel. If we assume that steel at a white heat is a mass of spherical molecules in a plastic condition, their cohesion is due to the limited contact of spherical surfaces; but if we roll or compress this very hot steel, the spherical molecules become polyhedral, presenting facets (or flat instead of spherical surfaces) for cohesive contact, and if we do not continue this rolling or other compression until the steel gets red cool enough to "hold its work," the hot molecules will resume more or less their spherical shape when the pressure is removed. Hence, I prefer to cut specimens out of full size plates, bars or shapes, after the rolling is done, and the intention of the above specifications for materials is to legalize for the benefit of our inspectors about what we actually get out of the shops in general practice.

I am aware that in the foregoing percentage of increase or decrease in working and test strains, there is no bumper provided against sliding up or down into infinity; but the bridge engineers of this country are reasonable men and are very apt to use reasonable sections; and reflecting on this fact is what encourages me to hope that Mr. Waddell will be reasonable about admitting such a lengthy and discursive contribution to his "asymptotic curve."

By H. H. Quimby, M. Am. Soc. C. E.

If the details of bridge connections were thoroughly scientific, and secondary strains properly cared for if not eliminated; the intensities of stress as prescribed now and for some time past in railway work, would make the possibility of the failure of a bridge of modern design, under any conceivable load, so remote that laborious computations to find a possible slightly greater stress might reasonably be regarded as unnecessary refinements. But with specifications and practice as crude in the matter of details as they often are, it is only wise and prudent to provide for the greatest concentrations of the rolling loads expected to be carried, even if they are only two per cent. greater than the approximations.

Specifications which are minute in respect to loads and unit stresses, in many cases ignore important and even vital considerations. The disastrous collapse of a railway bridge in Europe a few months ago was, by some engineers, attributed to the faulty connection of the lateral bracing to the trusses, and similar reasons have been given for the fall of bridges in this country. The trusses and lateral systems may be proportioned for their given loads without allowance being made for the fact that one system can operate to complicate and interfere with the action of the other. The bending effect of both end and intermediate sway bracing on the posts of through spans is often serious. The engineer who prescribes a given wind load to be carried down a certain post, may, without perceiving the anomaly, permit the builder to proportion the post for compression only and to treat it as being fixed at the point of attachment of the sway bracing, thereby reducing its ratio of length to radius of gyration. We hear objections to the detail of riveting floor beams to posts because the deflection of the beams springs the posts out of a true line, although the fastening is ample to keep the post in the control of the floor beam, and make its lower end absolutely fixed. The danger from poorly designed or improperly adjusted transverse bracing is vastly greater, but is often overlooked.

This subject, together with Mr. Waddell's declaration of hostility to adjustable bridge members, recalls a case wherein the intermediate sway rods of a through span—which were attached to the posts a short distance below the top struts—had been screwed by the erectors so tight that they had sprung the top ends of one or more of the posts out of line enough to excite the surprise of the inspecting engineer that the bridge had not collapsed. A bridge should be designed so that its safety cannot be imperiled by a lack of judgment on the part of erectors. This incident teaches also that it is of the highest importance that careful attention be given to proportioning the jaws of posts, particularly such as have their flanges cut away to facilitate the chord packing. A safe formula for the jaws, deduced from experiments on full size pieces, is as important as one for the section of the member, and as the work of clipping, punching and riveting generally tends to curve these jaws, their inspection is equally important.

By John A. Fulton, M. Am. Soc. C. E.

A.—LIVE LOADS.—It is a good practice to plot the engine diagram and train load to a scale of, say, ten feet to an inch, then on a separate strip of paper lay off the proposed panel lengths, and place the one under the other in such a position that the leading panel point shall come immediately under the second or the third driving wheel (it will not make much difference which) and distribute all the loads to the several panel points by the law of leverages. We then have a series of live loads equal in amount and very nearly equivalent in effect to the actual live load of engine and train, the leading load in this series being considerably greater than any of those following. Then making no account of the counter effect of the small live load which always exists at the panel point next in advance of the engine drivers, slide this series of live loads across the strain diagram from panel point to panel point, assuming that the web shear under the leading load is the maximum on members leading from that point. In this way determine the shear on all web members, including the end posts. This method of using a fixed series of loads for a given panel length, regardless of the number of panels in the bridge, may not always be strictly correct, and the position of the engine wheel base with reference to the panel point under it may not always be exact; but the method is easy of application and the results as close as we can proportion the sizes of material.

Having thus determined the vertical shear on the end post, find the bottom chord strain for the first one or two panels and add increments for succeeding panels to the center, precisely as for a uniform load which would produce that shear on the end post. At first sight this would seem to give excessive chord strains for all but the one or two panels at the end; but if it be borne in mind that it is not at all infrequent for the rear end of one train to be close against the front end of a following train when standing on a bridge or elsewhere, or that a dead engine is being hauled about the middle of a train, or, worse still, immediately behind the hauling engine, then it follows that for maximum chord strains at the center of the span the engine should be placed at the middle of the train instead of at the end. With the engine at the center of the bridge and the typical train immediately in front and behind it, the chord strains will be correct, as determined so easily by the method of increments above described.

For the maximum live load on a floor beam it is a simple and short operation tc slide the engine diagram back and forth over a panel point until the position for maximum effect is determined, and then distribute the loads to the floor beam by leverages as before described for panel loads.

In the case of deck plate girder bridges, the engine diagram, so placed on the strain sheet that either of the two central wheels shall be at the center of span, readily gives the maximum bending moment at the center, and the same diagram slipped along until either of these two wheels is at the quarter point of the span, gives in the same way the maximum bending moment at that point. A very quickly obtained, and perhaps sufficiently close approximation to the value of the bending moment at the quarter point, is reached by calling it 77 per cent. of that at the center of the span. Having, then, the bending moment at the center, at the two quarter points, and zero at the ends, and laying off these as ordinates from a straight line. and sketching a parabolic curve through them, we readily determine the bending moment at any point.

Placing the engine diagram so that the point driven is directly over (or rather just inside) the center of the base plate and distributing as before described, gives the maximum live load shear on the web. In the case of through plate girders with stringers and floor beams, the load should be distributed to the panel points as in a truss bridge. In any plate girder in which the web is spliced, great care should be exercised to see that the splice has rivets enough to carry the shear at that point.

Concerning live loads generally, I am decidedly in favor of using every legitimate means for obtaining heavy bridges, since to add, say, 10 per cent. to the capacity of a proposed bridge does not add 10 per cent. to the cost of it. I would use for a typical live load, not an engine followed by a train of cars weighing from 10 to 20 per cent. less per foot than the engine, but a solid train of engines, and would figure the engines heavy enough to cover a good many contingencies not altogether foreseen just now. No one can safely predict what the engine of the future will be or that the tendency of the last few years to increase engine weights has reached its limit. Had the bridge engineer of twenty years ago made a fair allowance for the future loads on his bridges, there would not now be the necessity for replacing so many of them.

If all parties interested could be convinced that the typical live load should be a train of engines, then I should be in favor of using a uniform live load for web and chord members; but for floor beams, stringers and short span girders I would use actual concentrations as before described, or else such a uniform load as would produce strains equal in all cases to those produced by actual concentrations. The admirable series of typical engines proposed by Mr. Waddell would seem to leave nothing unprovided for in the way of live loads if he would leave off the train load and substitute engines instead.

The policy of the average railroad company, which unhesitatingly builds its embankments 16 feet wide and excavations 22 feet wide, either of which might be made less in the first place and increased at any time afterward if found too narrow, and yet shaves down the cost of an iron bridge to the lowest mark, is economically unsound. To strengthen it after completion will be expensive and difficult, if not altogether impracticable, and the company thus secures weak spots in its roadway at points where, of all others, it should have excessive strength, since failure at such points is sure to prove most disastrous. The saving is, perhaps, $10,000 on a $100,000 contract, where the rest of the roadbed costs millions. The typical bridge should not be a source of dread either to the public, who do not understand it, or to the employees who do.

B.—For wind pressure I would suggest 200 pounds per linear foot on the unloaded chord, and 500 pounds on the loaded chord (300 of this to be moving load) for all spans up to 150 feet. For spans 500 feet long I would suggest 350 pounds on the unloaded chord and 650 on the loaded chord, with some portion of this as above for moving load, and proportional amounts for intermediate spans. For the effects of wind load I would assume that all such loads on the top chord would pass through the top laterals and end posts to the abutments without relief from the vertical sway bracing at panel points; and would then make each interior set of sway bracing sufficient for a single panel, with the usual provision as to the minimum size of material to be used, and would assume the indirect effect on the bottom chord to be uniform from end to end of span.

C.—I would use plate girders up to 80 feet, riveted Warren through girders from 80 to 125 feet, Pratt trusses from 125 to 225 or 250 feet, and subdivided Pratt trusses from that up; but see no serious objection to a

lattice deck bridge of two systems of triangles, provided they are not run together into one system just before reaching the abutments.

As to spacing of stringers and webs of plate girders, 6 feet 6 inches has to recommend it a reasonably small bending effect on the ties under ordinary conditions, and a reasonable safety for the outside wheel of a derailed truck. To use outside stringers that can be called into action only in case of derailment is clearly to waste material. Oak bridge ties 8 x 8 inches x 11 feet, notched one-half inch over stringers and spaced 12 or 13 inches center to center, with oak guard rails 8 x 8 inches at the outer ends of ties, either with or without inside guard rails, make a stiff floor, and are not cut to pieces by derailed wheel flanges, as would be the case with white pine ties.

D.—INTENSITIES OF WORKING STRESSES.—In test specimens we may require an elongation of 20 per cent. and ability to stand a sharp bend without sign of fracture, but in bridge wrecks we do not find any such elongation nor any such bending. Doubtless, the difference in treatment is the cause of the difference in results. Attempt to cut ordinary molasses "taffy" with a knife or to twist it or pry it apart and the task is quite troublesome, but strike it with a light hammer and it is found to be about as brittle as glass. The former experiment shows how we test material, the latter shows how we use it. If some one would devise a scheme for testing bridge members which would treat them about as they are treated in a bridge, the results of such tests for elastic limit and for ultimate strength would be exceedingly valuable to the bridge designer, but they might differ somewhat from the values generally assumed.

To illustrate an important point, assume a Pratt truss of ten panels with a uniform live load advancing over it. Leaving out of account the effect of dead load, the vertical shear on a theoretical counter in the second panel will be one-tenth of a panel load; that in the third panel will be three-tenths of a panel load, but the increment is only two-tenths, the other one-tenth being already in that member. Proceeding onward to the end post at the further end of the span, we find the vertical shear on that member is forty-five tenths of a panel load, of which only nine-tenths of a panel load or 20 per cent. of the entire load is the increment, the remaining 80 per cent. being already in the member from preceding loads; and whatever the number of panels, it is evident that the increment will never quite equal one panel weight. Now it seems clear that when the end post gets its maximum live load, this maximum load will consist of nearly all of the last panel load, plus the impact for that amount of panel load, plus the proportional amount of all preceding panel loads without impact; since the effect of these preceding loads has reached the end post before the strain on it had become a maximum, and has reached it not suddenly, but gradually.

It should also be borne in mind that the shear from loads near the rear end of the span reaches the forward end post through a series of interior posts and diagonals equivalent in effect to one very long, and therefore elastic member. If this view be a correct one, then the effect on the end post of any bridge from each ton of live load is but very slightly in excess of that for each ton of dead load, or, in other words, the impact due to high speed counts for a relatively very small amount on the end posts, but increases toward and becomes a maximum at the first (theoretical) counter. It would therefore seem that in proportioning the web members of a truss

this variable effect of impact, a maximum at the beginning of the span and a minimum at the end of it, should be the measure of intensities of working strains on web members.

I would suggest that the web strains be determined by any satisfactory method, making due allowance for the negative effect of dead load on counters, and that the strains thus obtained be then increased by percentages determined as follows: Let n = the number of panels in any truss, and n — 2 = the number of panels requiring an additional percentage. Then $\frac{100}{n-2}$ = the increment to be added at successive panel points.

Take, for instance, an eight-panel bridge. Then n — 2 = 6; $\frac{100}{6} = 16\frac{2}{3}$; hence, the percentage to be added to the strains on the six interior panels will be respectively $16\frac{2}{3}$, $33\frac{1}{3}$, 50, $66\frac{2}{3}$, $83\frac{1}{3}$, 100; or approximately the strains on the main web members will have their amounts increased from 0 at the end to 50 per cent. at the center, and on counters from 50 per cent. at the center to 100 per cent. at the end. With strains thus increased it would be proper to use a constant intensity of say 9,000 pounds on main members, and for additional security 8,000 pounds on counters.

Concerning formulas which involve both the maximum and the minimum stress, if a given truss rod is to have a maximum strain of 50,000 pounds and a minimum of 20,000 pounds, while another rod is to have a maximum of 50,000 pounds and a minimum of 1,000 pounds, it is not quite clear why there should be any difference in the size of the two rods, unless we are ready to abandon the theory that iron not overstrained is permanent in strength.

Another idea occasionally appearing in bridge literature, with seemingly not sufficient cause, is that because a certain excessive strain is likely to occur only at long intervals, it is therefore not objectionable, while, if it were to occur at short intervals, it must be provided for by using additional sectional area. If we are proportioning our bridges for certain train loads with the idea that these bridges are sufficient for the purpose, but would not be sufficient for a continuous series of such trains hour after hour and day after day for an indefinite period without any deterioration whatever except for the wear of the elements, then, in the interest of those who have to pay for these bridges, it would seem that our unit strains must be too high and ought to be reduced. An organic body existing by the daily destruction and renewal of animal tissue may become "fatigued" by work which is far within its safe capacity and may require rest, and is certain to enter into a long rest within a very limited period; but it would seem that no such doctrine as this could be applicable to iron and steel, which have nothing within them to require renewal.

E.—As to combined stresses, where wind stresses and load stresses both occur in the same member and are of the same kind, I would determine the sectional area required for each and add the results. If it be good designing to allow chord members to be overstrained 20 or 25 per cent. during wind storms, why not reduce the sections of web members to correspond? It would seem that a bridge might as well be weak or might as well fail in one place as in another. As to bending of end posts on account of wind strains, if end floor beams be used and well connected to the lower ends of end posts by means of gusset plates, it would seem fair to consider the lower end of the post as fixed, and thereby reduce the lever arm of the bending moment 50 per cent.

F.—In plate girder proportioning I would advise the use of nothing less than three-eighths inch for thickness of web plate. Whatever its thickness, it should have sufficient net area to resist the vertical shear at any point with a low unit strain and should have sufficient bearing area for the rivets in any portion of the flange. In long shallow girders this will require a web much thicker than three-eighths inch. One point often overlooked in plate girder designing, in fact it is perhaps generally overlooked, is the thickness of wall plates and base plates at the ends of a girder. Many girders having a bottom flange consisting of two angles and one or more cover plates, have the first cover plates say three-eighths inch thick made the full length of the girder, and dispense with a base plate altogether; thus using material where it does no good and omitting to use it or not using enough at the place where it is needed. On account of the deflection of a girder under a load, the inner edge of a base plate is certain to get more load than the outer edge; it is desirable, therefore, that the end bearing of a girder be made as short as practicable lengthwise of the girder, and spread out laterally for the necessary bearing area. It seems entirely possible that the plate girder of the future will be built on a rocker bearing, to secure uniformity of pressure on the masonry as in a pin-connected truss. The projecting part of a wall plate or base plate should be figured as a solid shallow beam with a uniform load pressing upward, and the base plate should be well riveted to the bottom of the flange angles or it will lack much of its supposed stiffness. In order to have a base plate well supported it is necessary to use web stiffeners of ample projection, and that these stiffeners be so placed that they will distribute the load over the base plate to the best advantage.

In the designing of floor beams, it would seem difficult to devise a worse arrangement than that of destroying the floor beam web in order to run the bottom chord through it instead of over or under it, and then patching up the weak spot by the queer devices sometimes used. There would seem to be no difficulty in building floor beams with flanges parallel between trusses, and then riveting them between the posts above the bottom chords where practicable, or below the chords if desirable, extending the posts for that purpose to the bottom of the floor beam, but riveting the connection in all cases. If the longitudinal strain from lateral rods would produce too much bending strain on the posts, the difficulty could be easily remedied by using light tension members, connecting the foot of the post with the bottom chord pins at adjacent panel points after the manner of the Fink truss.

By Benjamin Douglas, M. Am. Soc. C. E.

It is not quite as simple a matter as Mr. Waddell thinks to find a uniform load which will cause the same stresses in all the members of any span as will a system of concentrated loads. That a uniform load can be found which will cause nearly equal maximum shears and bending moments is true, as has been shown, and in a Pratt truss with parallel chords the maximum stresses in the members will also be nearly equal for the two systems of loading. In compound trusses, however, when the entire shear or bending moment is not resisted by a single member, the relative distribution of the loads may be important and the uniform load cause maximum stresses differing much more from those caused by the concentrations. This is the case with the Whipple truss, for example.

In the following table are given the vertical components of the maximum stresses in the diagonal tension members of a Whipple truss having 10 panels of 25 feet each, computed for Mr. Cooper's "Class A" diagram, and for a uniform load of 3,112 pounds per lineal foot, which is given by Mr. Waddell as equivalent to the loading of the diagram:

Member.	Vertical Component of Stress in Pounds.		Percentage of Error.
	By Diagram.	By Uniform Load.	
1st Main Diagonal	177 500	155 600	12.3 Danger.
2d "	143 700	124 500	13.4 "
3d "	109 900	93 400	15.0 "
4th "	83 600	70 000	16.5 "
1st Counter	57 200	46 700	18.4 "
2d "	38 300	31 100	18.8 "
3d "	19 900	15 600	21.6 "

These percentages of error are certainly too great to be neglected, and while they are perhaps larger than would be found in most other forms of truss, they show, I think, that Mr. Waddell is mistaken in thinking that his assumption that the trusses are of the simple Pratt type with parallel chords cannot in any way vitiate the results of his investigations, and that we should not be too sure that a uniform load which is equivalent to engine concentrations for one form of truss will be so for any other we may be considering.

It would save some labor to computers if every railroad company would adopt one of a series of standard live loads in designing its bridges, and I see little to criticise in those proposed by Mr. Waddell, except that the weights on the tenders are too small, and there should be an alternative load corresponding to Mr. Cooper's 100,000 pounds on two axles. It is true that this is not needed for long panels, but short ones are necessarily used occasionally, and the specified loads should be such as to provide for them.

What is said about wind pressure is in general in accordance with my views, but the overturning moment of the wind pressure on the train should be considered as well as that on the top lateral system. I am not yet prepared to adopt riveted laterals throughout, although they have strong points in their favor. When used between compression members, they must either be made stiff enough to act in compression, or they will be slack when most needed. If they are made stiff, they will be very heavy compared with rods for short spans. I do not agree with Mr. Waddell in thinking that no railway specification begins to cover the ground of proportioning the inclined end posts of through spans, to transfer the wind pressure on the upper lateral system to the masonry. Many of them say that the combined unit stresses shall not exceed a certain limit for this or any other members of the bridge, and I think that covers the case. It does not seem necessary for the railroad company to tell the contractor how to compute the stresses. The latter is supposed to know that.

I, too, firmly believe that the proper way to proportion the section of a plate girder is to count in the web as aiding in resisting bending moments, but do not think that the rule given for finding the total moment of resistance is sufficiently accurate. The moment of resistance of the web is substantially as given (one-sixth its area multiplied by the depth of the girder), but the actual moment of resistance of the flange angles is less than their area multiplied by the distance between the centers of gravity of the flanges, and in shallow girders the error is considerable.

Let $2\,d =$ depth of girder from back to back of angles,
$2\,h =$ distance between centers of gravity of flanges, and
$2\,y =$ depth of girder over all; then the true moment of resistance of the flange angles is $\frac{\text{area} \times h^2}{y}$ if we neglect the moment of inertia of the angles about their center of gravity. The moment of resistance by Mr. Waddell's method is area × h, which is greater than the actual moment. Assume a girder with a web plate 24 inches x $\frac{3}{8}$ inch, and flange angles 6 x 4 inches, weighing 20 pounds per foot. Then $2\,d = 24$ inches, $2\,h = 21.8$ inches, $2\,y = 24$ inches, area of one angle $= 6.0$ inches, and its moment of inertia about the axis through its center of gravity is 7.8. The true moment of resistance is $\frac{4\,(6.0 \times 10.9^2 + 7.8)}{12} + 24 + \frac{3}{8} + \frac{1}{6} + 24 = 276$, and the moment of resistance given by Mr. Waddell's rule is $4 \times 6.0 \times 10.9 + 24 + \frac{3}{8} + \frac{1}{6} + 21.8 = 294$, which is too large by $6\frac{5}{10}$ per cent. If we neglect the web, the moment of resistance found by multiplying the area of the angles by the distance between their centers of gravity is 262, which is not as much less than the real moment of the whole section as the other is greater. For deeper girders the error is less, but for shallower ones it is greater, and I have found cases where the true moment of resistance was less than the area of one flange multiplied by the distance between the centers of gravity of the flanges. These shallow girders, it should be remembered, are usually short, and should have an excess rather than a deficiency of strength.

By Samuel Tobias Wagner, M. Am. Soc. C. E.

Under Group "C," "Styles and Proportions of Bridges," the writer would prefer the following limits for the lengths of spans used in plate and lattice construction, namely: Plate girders up to 80 feet spans, lattice girders from 80 to 125 feet, at which latter point pin-connected trusses should begin to be used. The most serious objection to the use of plate girders from 80 to 100 feet is the necessarily great waste of metal caused by having a continuous web. As true engineering practice aims to produce the best construction for the least money, and as it is perfectly practicable to design a very rigid and unquestionably perfect lattice span of such lengths, with a saving of from 30 to 40 per cent. in weight, over the same length of plate girder span, and with much better and more pleasing general effect, we do not seem justified in making the customer pay the difference unless he has special reasons for doing so. Owing to the uncertainty of stress distribution in riveted connections, riveted spans should not be used except for lengths where pin spans are lacking in rigidity; and as pin spans can be, and are, designed with floor systems rigidly connected to the trusses and thoroughly braced with stiff laterals for spans of 125 feet, the writer would, for spans over this length, pass at once to pin-connected Pratt trusses, with panels as long as can be rigidly braced. He thoroughly advocates Mr. Waddell's claim for the single cancellation principle for all trusses as being the only really scientific construction, and much simpler and therefore better in practice.

Regarding adjustable members in bridges, the writer again believes Mr. Waddell to be on the right track. If properly designed for erection purposes, and carefully manufactured, adjustable counters can be made a thing of the past. There can be no question about the lower laterals being rigid, as no one who has ever carefully watched the action of poorly braced floor systems under heavy and sudden loading could long remain in doubt on this point. For long spans, at any rate, the top laterals should be of the same construction.

The writer is very glad to see that Mr. Waddell has advanced his opinion regarding the unnecessary reaming of rivet holes of mild and medium steel which will stand the enlarging of the rivet-hole 25 per cent. by means of the drift test successfully; and hopes that more of the members will put themselves on record in the same way. It has always seemed an insult to good metal to require reaming when the quality of the metal is such that no practical benefit is derived from it. The line, however, where the reaming becomes necessary should be carefully observed, and probably Mr. Waddell's requirements meet it as well, if not better, than any other way.

Now that eyebars are manufactured of widths up to and including 10 inches, it is advisable to use wider bars for long panels than was formerly the custom, and at the present time this is being largely done. By using a wider bar it is possible also to reduce the number of bars in a panel, the thickness of each individual bar, the bending moment on the pin and consequently its diameter and length. In making bars of the largest sections, special care should be paid to the tests, as special arrangements must be made by the manufacturer to cast special ingots, or use larger piles to insure the requisite amount of work in the rolls upon the metals. Steel bars of the larger sections specially are much more desirable in every way than iron, both in reliability and finish.

By William Cain, M. Am. Soc. C. E.

Whilst agreeing with Mr. Waddell in most of the points brought forward in his paper, I must take exception to the co-efficient ½ in his formula for unit stress,

$$\text{Intensity} = \text{constant}\left(1 + \tfrac{1}{2}\,\frac{\text{minimum stress}}{\text{maximum stress}}\right),$$

though I admit that, in the present state of our experimental knowledge, this co-efficient must be, to a certain extent, a matter of opinion. Still, as it has been assumed all the way from ⅓ to ⅔ by certain bridge engineers, it is well that all interested should give the basis, if any, of their assumptions, when possibly the range of permissible values will be restricted within much narrower and more manageable limits than at present. If we call the ratio of minimum stress to maximum stress θ, we can write the above formula of Mr. Waddell's,

$$\text{Unit stress} = \text{constant} \ (1 + \tfrac{1}{2}\theta),$$

which is Launhardt's formula (as given by Weyrauch) for, say, forty million repetitions of stress. For a less number of repetitions, it is found by working over the values given in the original experiments that the coefficient $\frac{1}{2}$ is decreased, and becomes quite small for a few hundred thousand repetitions, which is nearer the number to be provided for in our bridges than the former. The iron, in these experiments on direct tension, broke under a single application of a load gradually applied ($\theta = 1$) at 45,000 pounds; for millions of applications of a stress of 30,000 pounds per square inch (the stress varying from 0 to 30,000), rapidly repeated, the bar again broke. The above formula becomes for this case, unit stress $= 30{,}000$ $(1 + \frac{1}{2}\theta)$. For $\theta = 0$ we have 30,000, for $\theta = 1$ we have 45,000, and for intermediate values of θ the formula is found to agree with the results of experiments.

This iron was not such as we would use in bridges, and it is believed for iron whose breaking strength is 50 to 55,000 pounds, that this coefficient of θ would be smaller for the same number of repetitions. The loads were very rapidly repeated, and the conditions could only be paralleled, in a railroad bridge, by trains gliding rapidly, without appreciable friction or impact, in rapid succession across the structure. It is readily granted that these conditions do not obtain in practice, and yet it would seem that we have gained something valuable from the Woehler experiments that we should not throw away. We certainly should feel ourselves on safer ground by asserting (for a railroad bridge, the only kind I shall consider) with Woehler, that repetitions of a load will cause destruction sometimes when the load constantly applied will not, and I think this law holds true even where the loads do not succeed each other rapidly.

Now, what are the conditions for a railroad bridge when a train headed by a locomotive rolls over it? Prof. S. W. Robinson (in Transactions of the American Society of Civil Engineers for February, 1887) tells us that as the locomotive enters upon the bridge, and before it has reached the center, the deflection at the panel point nearest the center becomes a maximum, and that a rapid vertical and horizontal oscillation is set up, which continues until the train leaves the bridge. He experimented on spans of 128 to 189 feet, 13 open web bridges being examined, the records of horizontal and vertical deflections at each instant of the train's passage being graphically recorded by an automatic apparatus. It is possible that the increased deflection due to the train in motion over that for the train at rest, was due in part to the unsteady motion, not in a straight line, but deviating laterally and vertically from a straight line every instant; mainly, however, to the centrifugal force of the counter weights on the drivers, which hammer away at the rails at each revolution of the wheels. Professor Robinson found that the increased live load deflection for freight and passenger trains at usual speeds due to the motion, varied all the way from almost nothing to 28 per cent. Out of one hundred and ninety-three train transits observed, twenty-five gave unusually large superadded deflections, averaging 18.4 per cent.

The graphic records show plainly, I think, that the bridge has time to recover from the first "sudden application" of the load as the train advances, so that the superadded deflections due to the train in motion over those for the train at rest, when at the maximum, are due not to the "sudden application," but to impact and vibration from unbalanced weights and rough track. Now, if we call the extra stresses induced by the extra vertical deflection the amount due to impact, we have for these bridges to add to the stress caused by the live load at rest on a chord member, say, 18.4 per cent. to get that due to the impact of the live load in motion, assuming that the stresses in the chords are directly proportional to the deflection. This much is very simple, and if similar experiments were performed, for all spans, from 0 up to 500 +, we could quickly rid ourselves of part of the indeterminates of the problem that confronts us.

Having, however, got this far, shall we assert that there are no more stresses caused in the bridge members than those corresponding to this vertical deflection? Surely not, for the horizontal deflection (which was not insignificant) must cause additional stresses in certain members, and besides this, many members may be largely strained from the tremors caused by the bounding and bouncing of the train, whilst other members may be relieved at the same time, so that the result is not shown in the deflection to an appreciable extent. A vibration in a tie rod at right angles to its length (which we know occurs from the rattling often observed as a bridge is crossed) will cause additional stresses. These could only be ascertained by a direct observation of the elongations of a portion of the tie bar as the train passes.

Granting, then, that there are additional stresses to those corresponding to the vertical deflections, and that the repetition of stresses due to the passage of many trains a day will lower the working strength, what shall we allow for these influences? Here is where we can all honestly differ. Not knowing anything better than the Launhardt formula to express these influences, especially as its form commends itself for its simplicity, I shall write, for the safe stress in pounds per square inch, for wrought-iron eyebars in tension—

$$b = 10{,}000\,(1 + \tfrac{1}{2}\,\theta) \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

This allows for repetition and stresses caused by tremors not giving any vertical deflection, and assumes that these two influences combined in a bridge member are as hurtful as millions of repetitions rapidly succeeding each other, as in Woehler's experiments. To use this formula, we must add a certain per cent. of the live load to itself to allow for the superadded deflection due to motion. If we call A = stress in a lower chord member due to the weight of the bridge, B = ditto due to live load at rest, and Bp = superadded stress corresponding to the extra deflection due to the train's motion, then the cross-section of the member is given by the formula,

$$\frac{A + B + Bp}{b}.$$

But the same cross-section can be found by dividing the sum of stress due to dead and live loads both at rest by—

$$a^1 = 8{,}000\,(1 + \tfrac{1}{3}\,\theta) \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

$$\therefore \frac{A + B\,(1 + p)}{10{,}000\,(1 + \tfrac{1}{2}\,\theta)} = \frac{A + B}{8{,}000\,(1 + \tfrac{1}{3}\,\theta)}.$$

Thus, for the bridges mentioned above, $Bp = .184\,B$ = average stress due to extra deflections, as shown by the average of twenty-five experiments giving the largest deflections. As θ for these spans is about $\frac{1}{3}$, or $B = 2\,A$, on substituting these values we see that the equality above nearly exactly holds; in fact, the co-efficient of θ in (2) was formed from this equation very nearly. Formula (2) gives a range of stress for $\theta = 0$ to $\theta = 1$, from 8,000 to 15,000 pounds; but as this differs so little from the extremes 7,500 and 15,000, I prefer to write, for simplicity, in place of (2)—

$$a = 7{,}500\,(1 + \theta) \quad\ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

whence,

$$\frac{A + B\,(1 + p)}{10{,}000\,(1 + \frac{1}{2}\,\theta)} = \frac{A + B}{7{,}500\,(1 + \theta)} \quad\ldots\ldots\ldots\ldots \quad (4)$$

Subtracting (3) from (1), we have for the decrease in unit stress, due to impact, which causes extra deflection, over the live load at rest,

$$2{,}500\,(1 - \theta) \quad\ldots\ldots\ldots\ldots\ldots\ldots \quad (5)$$

For all dead load ($\theta = 1$) this becomes 0, and for all live load $\theta = 0$, it reaches its maximum, as should be the case. For intermediate values of θ, this term varies directly with θ, which is certainly the most simple supposition to make. As it is interesting to see what values of p we obtain from (4), for chord members for various spans, I have given them in the table below, for assumed values of θ:

Span in Feet.	θ	p.
20	.10	.30
70	.20	.28
150	.33+	.25
300	.50	.22
450	.66+	.20

This allows a little more for the 150-foot spans than the $.184 = p$ first taken, which is not to be regretted, as on some of the bridges the deflections due to motion were over the average taken. The formula (3) above was deduced for a lower chord member. A similar method applies to upper chord and batter braces, with the modification due to the use of column formulas. For counters and middle ties $\theta = 0$, giving $p = .334$, or slightly over the .25 above for a 150-foot span, which is not to be regretted, as these members should have a slight increase in their section due to their small size and greater lateral vibration. For intermediate ties and posts the unit stress increases pretty regularly from the center to the ends, as it undoubtedly should. The exceptional decrease in unit stresses for counters and main ties is thus a strong point in favor of the formula in place of telling against it.

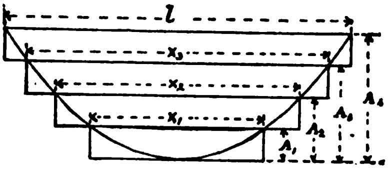
Nothing has been said, so far, about the mild steel now used in bridges, but the same reasoning would lead to a similar formula to (3) only with the constant 7,500, and possibly the constant θ slightly increased, if we are to consider at all Weyrauch's formulas corresponding to (1), where for millions of repetitions of stress, the co-efficient of θ for steel, having a breaking strength of 100,000 pounds, was found to be six-fifths in place of the one-half used for iron. As before stated for iron, the conditions of the experiments are not those of members in a bridge, but there is of course repetition of stress in a bridge member, and these experiments give us some insight into its effect, and should help us in coming to a somewhat safer conclusion. Finally I should say that if (3) is modified, it should be in the direction indicated by Mr. Waddell, by decreasing somewhat the coefficient of θ, for reasons apparent from what has preceded.

By Frank C. Osborn, M. Am. Soc. C. E.

A full discussion of the subject brought up by Mr. Waddell must be productive of much good to designers, builders and users of metal bridges. The railway companies in particular will be the gainers in any movement resulting in a greater uniformity in specifications and consequent diminished cost of estimating, for while the expense of estimating and designing is borne by the bridge companies directly, it certainly enters as an item of cost and is paid eventually by the railway companies.

The method given in the paper for finding the concentrated load at a floor beam by the use of the equivalent uniform load for a span of two panel lengths can hardly be called new, as it was in use by Mr. Edwin Thacher at least as far back as 1885. Regarding the determination of the lengths of flange plates for plate girders, Mr. Waddell remarks: "The moment parabola referred to affords a very expeditious method of ascertaining the proper lengths of cover plates." From this it seems that Mr. Waddell has not seen the very neat and expeditious method given in Mr. Thacher's pamphlet on the slide rule. This method is based on the equation of the parabola, and is as follows:

Let x_1, x_2 and x_3 represent the lengths of plates required. Let A_1 represent the area of the outer plate, A_2 the area of the outer two plates, and A_3 the area of the three plates. Let l = the length of span, then



$$x_1 = \text{length of outer plate} = l\sqrt{\frac{A_1}{A_4}}$$

$$x_2 = \text{" 2d "} = l\sqrt{\frac{A_2}{A_4}}$$

$$x_3 = \text{" 3d "} = l\sqrt{\frac{A_3}{A_4}}$$

Now, for any given case, A and l are constant, and the values of x_1, x_2, etc., may be obtained by means of the slide rule directly and with a single setting as follows: Set A_4 on slide to 1 on scale of roots, then opposite A_1, A_2, etc., on slide read x_1, x_2, etc., on scale of roots. These lengths, x_1, x_2, etc., are of course the theoretical lengths for a true parabolic curve. The actual lengths should, as usually specified, be at least 1 foot more than those called for by the above formula.

The method of obtaining end shear in plate girders is simple and easy of application, and the results certainly close enough for all practical purposes. The comparison of results obtained by means of diagram and by the uniform load is certainly interesting, and a strong argument in favor of the uniform load. The idea of half a dozen or more standard typical engines is an excellent one; those proposed by Mr. Waddell have the advantage of simplicity and uniformity in spacing, and should be approved by the engineers of the railway companies to the extent of adopting the one nearest their present requirements.

In regard to wind, the assumed pressure, for ordinary spans, of 450 pounds per foot for the loaded chord and 150 pounds per foot for the unloaded one, seems amply sufficient. For long spans, perhaps, this loading should be increased, but why not do it by means of a simple formula which will give the load per foot to be provided for in terms of the length of span? It takes no small amount of time to figure up the vertical projection of a long span truss, and probably not once in a lifetime will the wind strike the truss in the exact manner assumed. If an equivalent uniform load is admissible as a substitute for an engine diagram in the calculation of the principal members of a truss, and I firmly believe that it is, then a uniform load should certainly be good enough for such an erratic loading as wind pressure. The effects of the assumed loading should, however, be fully provided for.

The proposition to increase the clear width of through bridges to 16 feet for single track and 29 feet for double track structures is an excellent one, and the only objection to such a move, namely, the increase in cost, would be much more than offset by the additional safety secured. I agree with Mr. Waddell in a preference for a rigid lateral system.

The question of proper depths for eyebars of different panel lengths is an interesting one, and the following table shows the calculated fiber strains due to direct bending for the limiting sizes as proposed by Mr. Waddell:

Unsupported horizontal length of bar.	Minimum depth of bar.	Strain per inch, extreme fiber.
15 feet.	2 inches.	3 400 pounds.
17 "	3 "	2 900 "
20 "	4 "	3 000 "
24 "	5 "	3 450 "
27 "	6 "	3 650 "
30 "	7 "	3 860 "
33 "	8 "	4 100 "
40 "	10 "	4 800 "

When it is considered that these strains should be added to those due to the direct tension, and that the above table represents fairly the present practice, it appears that the question is a serious as well as an interesting one. In regard to spacing of stringers, I wish to express myself as decidedly opposed to stringers placed directly under the rail. In the first place, the impact of passing loads is given directly to the stringers and their connections. In the second place, the weight of floor beams is increased on account of the extreme leverage; and, thirdly, agreeing with Mr. Waddell, "outer stringers should be used to support the ends of ties in case of derailment," which adds still further to the weight, and therefore to the cost of the structure. The stringers should be at least 8 feet centers, and I think 9 is even better. With crossties 8 x 10 inches there is ample strength, and with the 1½ or 2 feet leverage, there is spring enough to the tie to take up a large proportion of the impact which otherwise would all go to the stringer. The short leverage gives a light floor beam, and the wide spacing obviates the necessity of outer stringers, so that on the whole the 8 or 9 feet spacing gives a better as well as a cheaper floor than one with stringers directly under the rails. I agree with the author in the preference for pine instead of oak for floor timber.

The question of just what unit stresses are proper for tension members in metal bridges can hardly be satisfactorily decided until exhaustive practical experiments have been made in this direction. The German experiments with repeated impacts are very interesting and valuable, but they hardly cover the case of bridge members subjected to a constant and sometimes quite large strain per square inch from dead load, and then subjected to an additional live load strain. We should have a number of experiments in the way of delicate measurements on stringers, beams and eyebars of bridges under engine loads at various velocities and passing at various intervals; and also a series of tests on specimens subjected to a steady strain, together with suddenly applied and released loads; the proportion of steady and sudden load to vary, and also the time between the impact load.

For unit strains in compression members my preference is still for the general form of Gordon's formula, and I am inclined to think that the discarding of this formula by some of our most prominent bridge engineers was due to a too hasty conclusion in regard to practical experiments. Mr. Thacher's "straight line" formula does, of course, agree very well with the experiments; from its construction it should. The theory of Gordon's formula, however, assumes a condition of the metal corresponding to strains within the elastic limit, and we know that when a column has been destroyed in a testing machine, the elastic limit of the metal has long been passed. Should we then say that Gordon's formula is wrong because a column fails under a condition of affairs entirely foreign to the basis of the formula? I should not think so, but would rather think it better to make careful and delicate measurements during column tests, before the metal reaches its elastic limit, instead of basing a formula on ultimate failure.

In regard to plate girder proportioning, I think it would be much better to keep the compression flanges within twenty diameters rather than let them reach thirty. The latter is I think too much. I will take this opportunity to protest against the practice of making the top and bottom flanges of plate girders of different areas, instead of proportioning the tension flange, and then making the compression flange of the same gross area. As plate girders are usually figured, the bending moment is divided by the depth center to center of gravity of flanges, in order to get the flange strain; this flange strain is then divided by the unit strain specified in order to get the desired area. Now, suppose the given specifications would require a larger area for the top flange than for the bottom: the center of gravity of the girder as a whole is thereby raised; and if we then calculate our flange strains by means of the moment of inertia of the section, which is quite proper, we find a larger strain in the bottom flange and a smaller one in the top than required by our given specification.

If different areas in the flanges are desired, then they should be obtained by using the moment of inertia of the section instead of by dividing by the depth of the girder, as is ordinarily done. When the web is one continuous sheet, I think it perfectly legitimate to count one-sixth of it as flange area; when very deep and relatively thin and with frequent splices, I do not think it is advisable to count the web, except for shear.

By W. H. Breithaupt, M. Am. Soc. C. E.

The interesting paper under discussion advocates some sound principles of construction which it is to be hoped will be more generally followed than they have been. Whether a uniformity in specifications and design among bridge engineers, much closer than it is, will yet be arrived at, even should close uniformity be desirable, is questionable. Since the beginning of iron bridge building there has been an approximation to uniformity in design, at least among American bridge engineers. Any advance that has sufficient merit is soon generally adopted. So much is this the case that the design of a bridge will generally tell approximately the date of its construction. No department of engineering has experienced greater development during the past fifteen years than this, and with the constant improvement in material and the advance in the governing conditions, it is futile to think that we have arrived at anything like a finality. Individual differences of opinion, too, will no doubt continue to exist even in so exact an art as bridge building has become.

Mr. Waddell makes extended argument in favor of the equivalent uniform load method of calculating stresses. The determination of stresses is a small part of the complete designing of a structure. With a slide rule and a table of squares the stresses are generally soon figured by any of the various methods individually preferred. But for ordinary fixed spans the method of moments some time ago described before the Society ("Cooper on American Railroad Bridges," July, 1889) is not only more exact, as is admitted, but requires considerably less work; I think I am safe in saying that it is the one most generally used now. The making of the single diagram used in the moment method can be done in, say, one-quarter of the time required for getting up the several tables of equivalent uniform loads that would have to be used.

Fig. 1 is a typical moment diagram, with quantities as affecting one truss, made on a scale to be conveniently applied to the skeleton of a truss. The upper two lines are essential, the others are added for convenience. The successive moments on the diagram are quickly obtained by adding to the moment up to any point the product of the total loads up to that point by the distance to the next one. Unequal panel lengths do not affect the facility of application of this method, as separate panel concentrations are not used. Long spans make practically no difference. When the chords are not parallel some extra work is required for obtaining web stresses in locating the intersections for origins of moments. For the case of some of the leading loads being off the span the proper moments are obtained, again from the diagram, by two simple subtractions. The moving load railways can carry is not now so much a question of bridges as of track, which latter seems to be about taxed to its limit by the present heaviest moving loads, until radical changes are made. Regulation of loads must be considered as outside of the province of bridge engineers. What they can do, as has been stated, is to design for proper proportion, which may be assumed to remain fairly uniform, of excess of concentrated load to general load, so that bridges may remain uniformly strong throughout. As to wind pressure, the assumption of fixed loads per running foot, as often specified, should not be applied to spans of over 200 feet in length, taking for longer spans a pressure per square foot of surface, and considering effective surfaces by the method as given in the paper, which is a good one. The more rational way of considering the overturning effect is that it travels partly by top chords through the portal and partly directly to the bottom chords, and provide for this overturning effect in the bottom chords by means of a large unit strain.

Riveted pony trusses have their proper place, where deep floors are admissible, for spans of from 100 to 125 feet. It is true that with shallow floor beams with chord brace to bracket extensions on beams, the deflection of the beams may injuriously vibrate top chords; this condition should rule out this class of bridge. When it can properly be used, a pony truss with its heavier sections and greater compactness will be more rigid and as economical as a high overhead braced span of the same length would be. Reduction in cost of material and consequent proportionally greater saving if shop work is reduced, as well as considerations of efficiency, have strongly tended to simplification of design. One manifestation of this is in the use of the present long panels. The use of a few bars of large section instead of more of smaller section is for several reasons desirable; but for prevention of sagging in the bottom chord bars, increase of section is not required and is not as effective against either

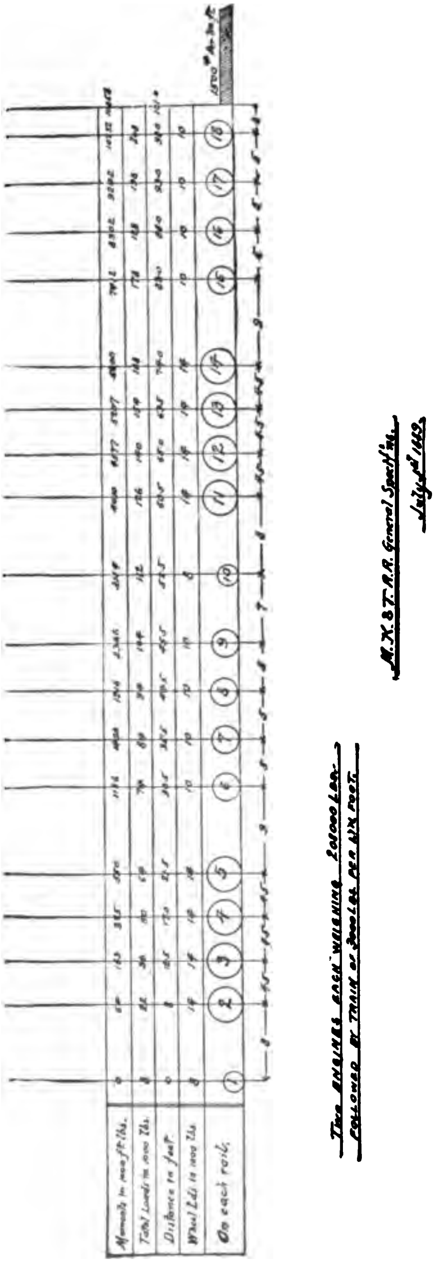


FIG. 1.

sagging or vibration as are mid-panel brackets now used for supporting chord bars. Such brackets are an extension of transverse brace frames between the stringers.

The author gives a bridge floor which is in many respects a good one. Oak is more generally used for ties and guard rail than pine, but good pine is to be preferred. For guard rails pine is particularly preferable, as it is almost impossible to keep an oak guard rail straight. Oak and pine should not be used together, as the acids from the oak will destroy the pine. Preserved woods are strongly to be recommended for bridge floors. For the best floor the stringers should be directly, or almost so, under the rails, as otherwise the ties will deflect. Then there should be outer safety stringers under or directly outside of guard rails. The inner guard rail should be a railway rail, which may be of lighter section than the regular rail used. The dapping of the guard rail is depended on for preventing bunching of ties; a bolt to every third tie will properly hold down the guard rail. Some form of nut lock is essential for all bolts in the floor or elsewhere about a bridge, as without it nuts will invariably work loose. This is something that is frequently neglected.

Under intensities of working stresses the author gives the well-known Launhardt formula. The formula is not much used now in this shape; but its principle is, in a more readily applicable way, by using greater unit strains for live load than for dead load.

To use end floor beams is the proper thing to do. Besides the advantages in their favor mentioned by the author, there is this, that they obviate injurious hammering of the masonry, which takes place when end stringers rest directly on it. It often occurs that floor beams have to be reduced in depth at their ends to fit them to the posts or to clear the bottom chords. Efficient reinforcement to effect this, when reinforcement is required, can generally be accomplished much more economically than by going to the extreme of running an intermediate flange the entire length of the beam.

The author's remarks on eccentricity of connections and on induced bending moments by certain groupings of rivets are strongly to the point. It is to be regretted that he has not said something on the disputed question of impact. The effect of impact depends on the speed of the moving load and on change in direction of surface from the ground to a bridge and on a bridge; but how much should properly be allowed for this effect is as yet a matter of conjecture only. It is a minimum when the floor system is stiff and rigid and deflects very little under moving loads; with a surface which changes direction only very gradually, if at all, and is, as near as can be, a straight continuation of the ground surface. In painting, another subject not mentioned in the paper, there is to be said that the use of oxide of iron paints, now so general, is much to be deprecated. The pigment in these paints is simply rust, which on iron or steel tends to induce more rust. Lead oxides, or carbonates, such as red lead and white lead, and linseed oil, should be used.

By Frank W. Skinner, M. Am. Soc. C. E.

Without entering upon the mathematical deductions of this very comprehensive and valuable paper, I wish to discuss some principles and practical considerations.

LIVE LOADS.—I believe in the use of engine excesses and real train values for the computation of live load strains; these should be assumed for present or future conditions of traffic, and those data selected which will give the maximum; so that different loads as well as different positions of the same loads may be required to give maximum results for different parts of the structure, each of which should be proportioned for its maximum. This leaves no uncertainty; the definitely stated problem is accurately solved. By the equivalent distribution system only one of many possible conditions is assumed, and an approximate equivalent is substituted for that.

A prime function of any constructing engineer is to make the most careful and accurate assumptions, founded on skill and experience, and then prepare exact computations therefrom. Exact computations are complained of as laborious—so is most valuable engineering work; but the mathematician is only a small part of the engineer; and the bridge concerns that compute and build four-fifths of the railway bridges, have special computers who are continually employed solely on strain sheets. Economy should be practiced in restricting the useless multiplication of designs and estimates by unsuccessful bidding on the same structure, by inviting bids from only a limited number of select, responsible parties.

WIND PRESSURE.—This is usually considered as dead and live load; should it not also be figured for the impact that it undeniably exerts through sudden gusts?

PROPORTIONS OF BRIDGES.—Under certain conditions the inclination from the vertical, of the planes of the main trusses of long spans, so that their cross-section is somewhat like a truncated inverted V, is worthy of consideration as affording economy of upper lateral and floor systems and increasing the rigidity. Mr. Waddell's plea for properly designed floor systems, protection and rerailing apparatus, cannot be too strongly endorsed. I believe the tendency is toward the use of too heavy eyebar bars. When a bar exceeds 10 inches x 2 inches x 40 feet, it is very doubtful if the steel of which it is composed receives sufficient work in its reduction from the comparatively small ingots generally used; and, so far as I know, cross-sections of that size never receive any edge rolling after leaving the blooming rolls, as I believe they certainly need.

INTENSITIES OF WORKING STRAINS.—I think that the author has overlooked the results, occasionally reported, of tests upon bridge members after having been a long time in use, and I should be glad if railroad bridge engineers could furnish more of them as their bridges are renewed. Such tests would be of especial practical value if they could be accompanied by the length of service and the original tests of the same material when manufactured. I would like to know what provision is allowed, and what, if any, experiments or observations have been made on the effect of impact strains added to existing heavy static strains. It does not accord with our theories of steel to suppose that tension members built of plates and shapes are as strong per net square inch of cross-section as are eyebars, because shapes and wide plates are not expected or generally required to give as high unit strength in small test pieces as flats and rods do. They cannot have their strength increased by reworking, and if injured at all by punching, shearing, etc., they cannot be restored, as are eyebars, by annealing.

COMBINED STRESSES.—I should like to see the proof that the addition referred to of 17 square inches of reinforcement to the section of a bridge post could increase the working strains so enormously as 18 per cent.

PLATE GIRDER PROPORTIONING.—I endorse the limitation of the number of flange plates allowed, and think that part of the chord section may often be advantageously disposed in web plates.

It is doubtful if it is desirable to have the best machine driven rivets 6 or 8 inches long between heads, and it is certain that a hand-driven rivet of that length is very imperfect. It is also evident that rivet holes which would match pretty well for two or three plates would require much more reaming, and considerably weaken the section when carried through a high pile of plates. Inspectors will sometimes condemn machine-driven rivets for slight eccentricities of head, etc., when they can be replaced only by hand-driven rivets that are incomparably worse, to say nothing of the injury done to the plates (especially steel ones), in forcing out a large, long, well upset rivet.

I shall be glad to see the detail that Mr. Waddell describes as having practically and satisfactorily accomplished the focusing of all lines of strain, at an absolute point at the center of a main truss lower chord connection. I do not wish to advocate the general use of suspended floor beams, but I think there may be conditions where a well-built suspended floor beam is preferable to one with a poorly riveted and poorly arranged rigid post connection. A prominent bridge company with which I was once connected imported and used soft steel almost entirely at that time. Much of the steel was Belgian shapes, and endured wonderfully severe cold bending tests. Angles and channels could be bent backward and almost tied up without cracking. Experiments were made with the use of these channels (heavy webbed 6-inch bars, as I remember) for floor beam suspenders. The channel bar was bent at the middle completely around a pin (slightly smaller than the required one). The ends were then brought down parallel, back to back, about three-eighths inch apart, so that their webs would rivet vertically across the end of the web of the floor beam, and the loop above, properly reamed out, would receive the lower chord pin. I do not know what the result of the experiments was, for I did not see them concluded, but I believe that the channels endured the treatment and made pretty stiff suspenders.

By A. J. Swift, M. Am. Soc. C. E.

Mr. Waddell's paper is certainly an excellent one in its scope, covering as it does many points upon which opinions differ among bridge designers and which are often discussed, but never before, it is thought, assembled in such form as to give the professional public a chance to express its views upon so many debated points all together, and in a form sure to meet the eye of the profession at large.

As one who has experienced the troubles noted by Mr. Waddell in using typical train and engine loads with exact wheel concentrations, I can heartily endorse what is urged by him as to the need for the use of a simpler form of load. I would suggest, however, as more consistent, in being nearer the facts of the case than a uniform load several times greater than the heaviest train in use, the often adopted expedient of a single concentration of the engine excess sufficient to equal a panel load (floor beam shear) arising from an ideal engine of sufficient weight to discount a considerable increase in gross weight of the heaviest type of engine to be used. This single concentration to be located for strains in web members, at the head of a uniform load, equivalent to a train similarly in excess of the heaviest train actually in use, and located, for chord strains, at any point in such a uniform train load. Also a single concentrated weight still greater than that above noted for calculation of strains in stringers, this latter weight to vary with the lengths of panels, and its amount to be based also upon the heaviest existing engine, with due allowance for future increase. For floor beams, it is thought that the well-known proportions between stringer shear and floor beam shear would suffice to insure sufficiently exact results. This, it is submitted, would seem to meet the difficulties as to complexity of calculation without going too far backward toward the practice of former days of using uniform loads only, and the consequent loss of view of the true form of the problem in hand. It would leave the general problem in its true form, without introducing annoying intricacies in calculation.

To any one who can recall the changes in opinion as to curved or other than parallel chords, floor beam connections, compression formulas and curves, the effects of live loads as compared with dead loads, etc., which have been noted within the past twenty years, and the diversity of view which now exists upon such points, Mr. Waddell's claim that there is such a thing as unnecessary refinement in concentration certainly recommends itself; and the fact that such points as the effect of wind in throwing excessive load from a train upon leeward stringers and floor beam connections has been neglected, while the effects arising from the same cause in towers and lateral systems has been carefully provided for, may also be noticed as warranting, for the sake of consistency, a less minute amount of care as to points like this, of concentration of rolling loads.

It is thought that no one will contest the truth of the ground taken by Mr. Waddell as to the advantage of using plate girders up to 90 feet span, although it seems apparently a step backward toward the days of tubular bridges; but it is suggested that some distinction should be made as to the different allowable spans of plate girders for double and single tracks, such as he has made, in regard to the length of lattice trusses. He has drawn the line in this latter connection, it is thought, at exactly the right point, but has not stated his reasons for so doing. I may be permitted to say, that a good reason for endorsing his views is, that the result of experience gained in keeping in repair a large number of riveted bridges for many years has been to show that the thickness of the iron used and riveted is really the controlling feature. This experience proves that well and heavily designed bridges of the lattice type and of recent date, in which connections of diagonals with chords through several inches of metal have been made by means of 1-inch rivets, have required greater care and more frequent renewal than those in which the rivets have passed through thinner metal, although the rivets in the latter have been under much greater shearing and bearing strain for many years. It would seem that the vibration of a web member in tension composed of heavy angle bars has seemed to fairly pry off rivet heads and loosen them, and that this really constitutes the limiting feature in such designs.

This being the case, it would seem that 70 feet for a double track plate girder span of either two or three girders is about the useful limit, and 90 feet for single track girders, with riveted lattice trusses (rather than the limits noted by Mr. Waddell), and pin connections for longer spans. The views expressed in this paper as to avoiding all pony trusses certainly seem sound, but an exception can be made, it is thought, in the case where floors can be made so deep as to give to the top chord the support of a stiff connection with the floor beams, whose top flanges are not more than 2 or 3 feet below them. This limit of the length of riveted lattice spans on account of the failure of riveting through thick iron at the connection of diagonals with cross chords seems to conflict with and render invalid Mr. Waddell's strictures upon lattice work of more than one system, since it often occurs that in the design of lattice spans, even of the length endorsed by him, two or more systems (up to four) have to be introduced in order to keep down this objectionable thickness at these points of connection. Furthermore, it is submitted that practically no trouble was ever found to result from the use of several systems, while certainly cases are on record, as witnessed by numerous photographs, where serious accidents have been unscientifically prevented by the aid given by one system to another disabled by a derailed train. This feature would seem to be the one really giving the lattice bridges the superiority noted by Mr. Waddell as existing over pin bridges in case of derailment. This increased safety is obtainable for pin bridges by enlarging the clear width between trusses so as to remove them beyond the reach of impact from a derailed train; it would therefore seem a pity to deprive the riveted bridges of this peculiar and great element of value.

The riveted lattice truss was the first step toward concentrating upon known lines the strains of unknown location and direction existing in webs of plate girders, and it does not seem clear that it is the true drift of bridge engineering now to try to force it (the lattice truss) to comply with the form found desirable in its offspring with pin connections. Furthermore, secondary strains at connections are lessened by keeping the members within reasonable limits of size, rather than increasing them as would be necessary if the form of truss were limited to the Warren girder. Rigidity also is of great value in preserving tie rivets in the chord connections of riveted work, much more so it is submitted, than with pin connections, and therefore shorter panels and consequently more systems seem justifiable. Again, one serious theoretical defect in lattice bridges is that the shear in passing from one diagonal to the next is necessarily carried by the chord as transverse strain, and this objectionable feature is certainly diminished by lessening the amount of this shear so carried at each section of the chord at panel points, this result being reached by the use of several, rather than one system. It is submitted that such views as those expressed by Mr. Waddell, and adopted in many lattice trusses, have resulted in structures which cannot be classified as "fish, flesh or fowl," the result being unfair criticism upon the excellent class of work of which these structures are not fair types; and that their manifest shortcomings almost warrant belief that, with few exceptions, designers accustomed to one form of bridge cannot properly design the other.

Exception, it is thought, may also be taken to Mr. Waddell's statement that plate girders should be riveted in full at the shops and not shipped in parts to facilitate erection. The difficulty in erecting whole a girder of 90-feet span, even for a single track, is very considerable, and it has not been found that field riveted work properly done is so inferior to that done at shops as to be inadvisable, if a sufficient excess in number of field rivets is allowed; while the danger of accident to large completed girders during transportation and erection is serious, resulting as it does from lifting them by improper points of support during transhipment and also at their destination.

As regards spacing track stringers or girders of short span, it is suggested that the points to be gained are a uniform support to a derailed train inside of the tie bearings on stringers, without the use of ties of unnecessary dimensions and consequently unnecessary expense; and that a distance of 7 feet between centers of stringers with ties 8 x 8 inches x 10 feet, accomplishes this result, and that, too, without going further than necessary in the direction of a return to timber floors resting upon stringers hung in the line of the chords, such as were more or less in vogue in the past. The additional expense for one renewal of ties upon bridges under my charge which would result from adopting Mr. Waddell's standards would be $33,000, a serious item if not really essential to safety.

In answer to Mr. Waddell's inquiry, I would say that a number of cases of split angles in top flanges of stringers and girders not properly supported by fitted stiffening angles, have been noted in work under my charge, and that on this account a proper provision of this kind seems very advisable at points throughout their length as well as at their ends; but it is suggested that their service in preventing buckling of webs over bearings and elsewhere would be as efficiently performed without this bearing upon flange angles, since the load which this fitting enables them to take is only that from a local application over them, while the instant before the wheel reaches this point, the web has to carry almost the same shear, and to resist almost the same buckling tendency. It may be allowable to add that during an experience covering a number of years, every case of failure noticed in iron bridges has been in the tension flanges of track stringers, which have been found from errors in workmanship or in original design to have been strained to 15,000 pounds and more per square inch of net section at the point of fracture; while truss members have been found in the older class of bridges which have been strained not less than 22,000 pounds per square inch hourly for years, and still have shown no sign of failure or deterioration when removed. This illustrates in a rough way, it is thought, the injurious effect (now so well recognized) of direct application of strain as compared with its more gradual application.

Numerous instances have been found, upon the other hand, when before reinforcement, top chords of old deck lattice spans of sections shown have supported ties directly, with a span between panel points of from 10 to 12 feet, and have shown no signs of failure after twenty years' service, although they were practically stringers with no bottom flanges whatever, and also strained as truss members. This fact is noticed merely as an illustration of the extremity which bad designing has reached in the past, and, it is feared, sometimes reaches even now; and to emphasize the fact noted above, that theories seem to fail in view of the known results of such cases of over-

strain, and that therefore it scarcely seems necessary to carry the refinement of concentration of rolling loads and their proper location upon bridges to obtain maxima strains, to the extent which has been customary and required in recent years.

Mr. Waddell's views as to rigid lateral systems and the advantages of unadjustable truss members have, of course, always been held by designers of riveted lattice work; and it has often been urged, with justice, that a considerable economy of material results from these rigid lateral systems, since both Warren girders of a double lateral system of this kind can be assumed to be under strain by wind load in one direction—one of each pair of intersecting members acting in tension and the other in compression.

His views as to spacing ties and the use of guard timbers have certainly the support of innumerable cases of safely carried derailed trains; but from the point of view of one wishing to incur no expense not demonstrated to be really necessary, I would suggest that a clear space of 6 inches between ties and a guard rail 6 x 8 inches, gained 1 inch and bolted to every third tie, seems from actual experience to provide amply against "bunching" under derailed wheels. It may be added that any spreading of guards at the ends of a bridge greater than the 8 or 9 feet of length of track ties is useless, since a truck off of the track and beyond the ends of the track ties would certainly sink in the ballast and overturn its car or break the couplings, so that no benefit would result from a further spread of the ends of the guards. Experience in maintaining iron bridges under heavy traffic fully justifies, it is thought, the use of end floor beams, since the direct impact of wheels upon the ends of stringers frequently shatters stone bearings or causes the bed plates of stringers to cut into them, resulting in bad surface of a track, and necessitating shimming under ties at the ends of bridges, which is certainly a most objectionable feature in their maintenance.

By O. F. Nichols, M. Am. Soc. C. E.

Undoubtedly much more can be accomplished toward uniformity in bridge designing by concerted action among engineers, more, I believe, through the report of a committee of the Society than through a general discussion like the one proposed by Mr. Waddell, which is bound to treat the subject in an unsystematic and necessarily rambling way. I do not mean that the report of such a committee should be made fast and binding, a mandate of the Society for all to follow; it would merely cover in the end the recommendations of the ablest of our engineers, members of the committee, and have such weight as their reputations and investigations would warrant, the Society acting as the agent for whom such investigations were made and by whom such recommendations were developed and announced.

It would certainly be well if some uniform system of loading could be agreed upon, simple enough to involve less loss of time in estimating on bridge work, a loss which is absolute to the unsuccessful bidder. The employment of equivalent uniform loads will probably help the matter somewhat; there are so many problematical contingencies in our railroad loadings and the chances are so greatly in favor of increased loadings, that it is well not to indulge in over-refinement in calculations, but to assume some gross figure sure to provide amply for the present and somewhat for the future, the error, if any, being on the side of safety; if the cost is somewhat greater it should be considered a wise investment. The extent to which material is forced out of some of our structures by refinements in calculations leaves them often without that mere mass of material which we now, more than ever, realize is necessary to the staying qualities required to resist impact, continuous pounding, alternation of stresses and numbers of incidentals to actual use which are difficult to estimate accurately.

I think it unwise to use metal less than three-eighths inch thick anywhere, on account of oxidation for one thing; our paints and painting are not improving as time goes on, and decay from corrosion is certain. When it comes to using five-sixteenths or one-fourth inch web and cover plates for girders, I believe the characterization "tin structure" is not too strong; thin cover plates are frequently distorted by oxidation alone. I think cover plates should be avoided wherever possible, and limited to one or two thicknesses of considerable dimensions wherever practicable; their action with the flange angles or channels is uncertain, largely from differences in elongation under stress due to manufacture, and they are by no means the protection against corrosion often supposed.

We, of course, know really very little of the actual behavior of web plates in practice; the most of the rules we have been using depend largely on Gordon's formula for columns and give results largely in excess of what we know to be required. It is unfortunate that extended and skilful experiments on full-sized pieces cannot be made. Some girders of good size were recently broken, abroad, to determine relative values of different materials, and no special attention seems to have been made of the action of the webs under stress. The translator says of one of the steel girders, "the web was bent out of its vertical plane," but how did it bend, did it buckle, and how much? In all probability it bent sideways with the failure of the girder, when the web came to sustain all the stresses in the girder. We do know that web plates will endure greater stresses than we have heretofore supposed. Mr. Cooper has recently sanctioned some quite bold practice in omitting stiffeners altogether from plate girders up to 4½ feet deep, and Mr. Thacher, in the "Buffalo Trace" viaduct, used girders 60 feet long and 5 feet deep without stiffeners, the web plates being one-half inch thick. The counter stresses of tension and compression, at right angles to each other in the web, operate more forcibly than we have supposed to keep the plate in vertical plane. The common allowance of 4,000 pounds per square inch for shear, and indeed all our allowances for shear, seem quite conservative as compared with allowances for other stresses.

The common rules for the use of stiffeners seem chaotic indeed; it is quite clear that they should be less than the depth of the girders apart at the ends of girders, otherwise the web, virtually unstiffened, sustains practically all the shear for a length equal to the depth of the girder at these points, and if it will do it for this length it will do it for a greater length, a reasoning which logically continued omits them altogether. If stiffeners are used I think they should be treated as posts and the web be considered as a tension diagonal only. In plate girder design we confuse the condition in which the flange needs the stiffeners, as in supporting a continuous wall of masonry with that of the railroad bridge where the tie is supported on an edge equal to the thickness of the web and the vertical legs of the flange angles.

An extravagant use of stiffeners has been introduced by some of the iron manufacturers; starting at the ends of girders with backs of angles facing from the ends, when the middle is reached instead of omitting them entirely as theory would dictate they double the stiffeners at this point, bringing the angles back to back and riveting them together, a keen sense of symmetry not permitting an otherwise possible saving of material.

I can see no good reason why we should hesitate in these days of perfect plates to increase the thickness of web to a reasonable extent. With flange angles one-half to three-fourths inch thick, why not have the webs of the same thickness if necessary, when (considering labor and material) we do not thereby materially increase the cost of the girders? The result would be stiffer and more permanent girders. Thin plates are bound to corrode to a dangerous extent long before the flange angles are materially weakened, unless they also are absurdly thin.

The stringer should be riveted in between the floor beams, wherever practicable, thus holding the latter vertical and avoiding a twisting in the floor beams, sometimes induced when steps near the bottom of the floor beams are used without such riveting. Provision for expansion can be easily introduced. I am glad to know that Mr. Waddell has abandoned views he once held as to placing stringers directly under the rail. Ties will not last as long under the combined decay of spike holes and support as girders at the same point. Suitable lateral bracing, which I prefer to place at intervals less than his minimum, and to which the floor system lends considerable aid, will prevent departure from a vertical plane in the stringers. The elasticity of timber should be utilized by wider spacing of stringers, to lessen the effect of impact and to avoid rigidity of track.

The floor system proposed seems a good one for bridges; the bolting errs, if at all, on the side of safety. I wish the spacing of the guard rail had been given, as this seems to be a point on which there is considerable difference of opinion. There should be room for the wheels to run between the steel rail and the wooden guard rail; and if inside and outside rails are both used, I think they should be spaced at different distances from the steel rail, the inside guard rail being nearest to the steel rail. I hope these points and the sizes of guard rails will be thoroughly treated in this discussion.

By Henry B. Seaman, M. Am. Soc. C. E.

At the Seabright Convention, 1891, a resolution was offered, proposing the appointment of a committee on bridge specifications, but it was withdrawn on account of the strong opposition manifested. This appeared to arise from a misconception of the duties of such a committee, and of the purpose for which it would be appointed. The work proposed was not merely that of formulating a specification, and making our "Transactions" "books of ready reference," but rather that of investigation, and accomplishing for this branch of the profession, what had already been done abroad by organizations similar to own own. In outlining the present paper, its author was, no doubt, inspired by the same motives of progress;

and while we contribute what we may toward the general discussion, we can but remember that any success here attained is but an indication of the more complete results to be attained by an authorized committee. The preliminary report of such a committee would take the subject up where the present paper must lay it down. The final report would be of incalculable value to the entire profession.

The subject of engine concentrations, as mentioned in the paper, has long been a vexatious one to calculators. The methods and results of exact calculations are attractive to those who have time and inclination to follow them through; but to others, who look upon this subject from a purely business standpoint rather than from a professional one, a shorter method is much to be desired. If railroads were able to adopt a fixed type of engine, and if it were possible for them to restrict themselves to the use of that type for all future time, the adoption of exact methods of computation, in new construction, would be justified; but when we consider that all successful railroads are progressive—that increased business requires increased weight of rolling stock, and that each new type of engine brings with it a new distribution of concentrations—the attempt to attain refined results for any particular type is a misconception of judicious design. If, then, we can attain an equivalent uniform load, which shall give approximately the desired results, its adoption is to be commended.

The illusion of the apparent refinement of engine distribution for new structures may be illustrated by the engines provided for in some general specifications. In these, the wheel spacing is given to inches, and the concentrations, in some instances, to 100 pounds. This refinement of weight will not hold true of different engines of the same type, and is worse than useless, as applied to various roads with various types of engines. When, in addition to this, the weights of tender are given—as often furnished by the manufacturer—with water, but with no coal, it shows that such refinement is more apparent than real.

A tender, when fully loaded with water and fuel, will have approximately equal weights upon each axle; but if the coal is neglected, being placed mostly over the forward wheels, these concentrations will differ by several thousand pounds. This is the condition, however, under which the weights are often furnished from the shops, and in several instances they have been introduced, without change, into bridge specifications. A tender, with water, designed for heavy consolidation engines, weighs about 18,000 pounds on each of the forward axles, and about 20,000 pounds on each of the rear axles. Add to this, 16,000 pounds of coal with which these tenders may be loaded by boarding up the sides, as is often done, and we have 23,000 pounds on each of the four axles. The tenders of the proposed typical engines would therefore appear considerably too light, particularly for the heavier classes. The weights on the pony wheels of the engines, on the other hand, appear excessively heavy, and would probably not exceed 16,000 pounds for the heaviest type.

In assigning the maximum concentrations to which bridges may be subjected in the future, we must consider the present conditions which are apt to govern them. The maximum concentration in use to-day is 40,000 pounds. This has been the case for a number of years on heavy passenger engines, and the roadbeds on several of the most important lines have already been modified to meet it. It also appears to be the heaviest concentration in use abroad, and it is not liable to be much exceeded with the present gauge. This, then, is the natural limit for the concentrations of consolidation engines, and it would seem better in outlining a set of typical engines to have this assumed as a maximum, and deduce the others by uniform decrements if desired.

The practicability of outlining a set of typical engines, as proposed, and formulating tables of equivalent uniform loads, varying with the different lengths of span, can only be proven by experience. It is doubtful whether they will prove attractive to maintaining engineers, for insertion in their specifications. These specifications are already growing very cumbersome, and to insert tables would only make them appear more so. It would probably be more practicable to insert one of these types, leaving the tables for use if desired. The most practical substitute for engine concentrations, for insertion in specifications, is the uniform load, with single concentration as proposed by Mr. Geo. H. Pegram, M. Am. Soc. C. E., several years ago. The reason that this has not already been widely adopted is because of the difficulty in ascertaining the equivalent uniform load and concentration, to correspond to a given type of engine.

The wheel spacing of the several engines, proposed by Mr. Waddell, appears to be well chosen; though the spacing between the drivers is usually 6 inches less than here shown. In advocating the adoption of equivalent uniform loads for bridge construction, it is not necessary, nor is it advisable, to abandon the system of engine concentrations in maintenance. Having a generally well proportioned bridge to maintain, it is the province of the engineer to ascertain as nearly as possible the actual strains to which it is subjected by the engines in use; and although our ignorance of the effect of impact prevents an exact knowledge of the results, it is always well to define the unknown factors as closely as possible, in order that experiment may gradually reduce these to a minimum.

The assumption that "in the near future, the material for the metal portions of railway bridges will be exclusively steel," seems to me a little premature. The objections to its use have not yet been removed; and although the development of its manufacture has enabled its production with as much uniformity and economy as that of wrought iron, it still has the same objectionable structure. The objection to the use of steel in railway bridges is that it resembles a refined, ductile, homogeneous cast iron, rather than a fibrous wrought iron; and although recent practice has gradually reduced the carbon until its composition approaches more nearly that of wrought iron, it has never yet been given a fibrous structure. It is to this fact that the present objection to its use is due.

Steel is objectionable because the least scratch, so fine as to be imperceptible to the closest inspection, may in time, under vibratory strains, lead to the destruction of the member. No inspection can be close enough to avoid this danger, and the reduction of the hardening elements does not eliminate it. This characteristic is due to its homogeneous structure rather than to its chemical composition.

Tests of steel under constant strain are of no value whatever as a criterion for its use in railway bridges. The development of a scratch under a single application of load would not be noticed. The chief care in the maintenance of iron bridges, and the one to which the closest inspection is directed, is the detection of flaws in details. A member rarely fails because of overstrained material. There are members in bridges which have been in use for years, with strains far exceeding those usually allowed, and which are safe; but there are details which, to all outward appearance, have been perfectly sound, but have suddenly developed flaws which, had they not been detected before the passage of a train, would have resulted in a bridge failure. It is for this reason that engineers hesitate to adopt a material the character of which favors the development of such flaws.

The general use of steel would seem objectionable for the reasons mentioned, but to cite the drifting test as an authority for its use without reaming would seem worse than to depend upon the single application of a load to show the development of slight flaws. "The standard drifting test" is of value only in discovering hard spots in the immediate vicinity of the hole, but cannot detect cracks or scratches caused by punching, the presence of which render reaming necessary. Enlarging the holes by drifting, forces the metal back upon itself, and tends to close rather than to open these defects. It may indicate soft material, as would also a tension test, but as a demonstration that soft steel does not require reaming the drifting test is a delusion.

The use of steel rails is sometimes cited as an argument for the adoption of this material in railroad bridges. When bridges receive the same incessant inspection in all their details, or when bridge members can be replaced as quickly and with as little expense as can a broken rail or splice bar, and when the failure of a bridge is attended with nothing more serious than a derailment—then may the general use of steel be advocated for railway bridges; but until this is true it is well to proceed with caution.

That the specification of 150 pounds per linear foot of chord for wind pressure, irrespective of the length of span or surface exposed, should prove unsatisfactory, is not surprising. The specification is not scientific, and like all empirical clauses is applicable only between limits. It should never be used in a general specification. The early specifications provided for a wind pressure of 30 pounds per square foot for truss bridges, and 50 pounds per square foot for unloaded trestles. More recently the latter pressure has also been applied to unloaded truss spans. It should not be expected that a review of older bridges would show them proportioned for the heavier pressure. The fact that the exposed surfaces of truss bridges of moderate span approximate to 10 square feet per linear foot of bridge renders the empirical wind specification convenient of application, but it should not be mistaken for a general clause.

The adoption of the right line formula for compression members, instead of the Gordon formula, as modified by Rankine, has become quite an engineering fad. It is no more accurate, and with the use of tables, now universally adopted, is no easier of application; but the profession has apparently become restless for want of a better formula, and, for a change, adopts an empirical one. The chief labor in proportioning columns is in the calculation of the moments of inertia (unless these, too, are tabulated), and from this r^2 as used by Rankine is more directly deduced than is the value of r used in the right line formula; and while the latter formula is purely empirical, that of Rankine is of thoroughly rational origin. The plea that the constants of the Rankine formula are liable to be varied and thus render the use of tables difficult, hardly justifies the adoption of a formula wherein even a greater variety of constants had been used.

The Rankine formulas, which are most recent, and now in very general use, are:

$$\text{Fixed ends} \ldots\ldots\ldots\ldots\ldots P = \frac{a}{1 + \frac{l^2}{36\,000\,r^2}}$$

$$\text{One end fixed} \ldots\ldots\ldots\ldots P = \frac{a}{1 + \frac{l^2}{24\,000\,r^2}}$$

$$\text{Hinged ends} \ldots\ldots\ldots\ldots P = \frac{a}{1 + \frac{l^2}{18\,000\,r^2}}$$

and for those who have no tables of their own, very convenient ones can be found on page 147 of "Carnegie's Pocket Book," edition of 1889, or later.

It is noticed that Mr. Waddell suggests the use of the Launhardt formula for truss members, but for girder spans and for details proposes constant allowable strains. If the Launhardt formula—and the principle of the fatigue of metals on which it is based—is true of truss members, it is even more true of the floor system and of details, and its omission in the one case would justify its omission altogether. The chief objection to the Launhardt formula is the amount of extra labor involved in its application, and it is probably for this reason that the proposition is made to restrict its use to the general parts of the structure. Another objection is, that it implies a definite knowledge of fatigue which we do not possess. In spite of these objections, however, the adoption of this formula was a marked improvement in the scientific practice of bridge construction, and it has caused modifications in most of the earlier methods of proportioning. It will probably remain in use until some equally rational, though less laborious, method is devised. An examination of Woehler's experiments indicates that it is quite as consistent with their results to consider the effect of live load as about twice as injurious, under continuously repeated strains, as that of dead load. Under these circumstances the dimensioning would be much simplified by the use of different unit strains for live and for dead loads, with proper provision for impact. To this end, Mr. C. C. Schneider, M. Am. Soc. C. E., has already framed a specification, in which he provides for the fatigue under live load strains by a constant in his formula for impact. In this respect his specification is probably the most advanced of any yet in general use.

By J. C. Bland, M. Am. Soc. C. E.

I heartily agree with Mr. Waddell as to the desirability of replacing the wheel load concentrations now so universally used in bridge specifications by another method. One, in my judgment, equally correct in results, is the use of a uniform load per linear foot of track, plus a concentrated weight. Such a method is, I think, easier of application than an equivalent uniformly distributed load as recommended by Mr. Waddell. The method I name is by no means new, for as long ago as 1875 I calculated a number of spans to the following specifications: "The strains on the trusses will be computed for the following loads: There will be assumed a moving load of 3,200 pounds per foot of track, on spans from 50 to 100 feet; 3,000 pounds on spans from 100 to 150 feet, and 2,800 pounds on spans from 150 to 200 feet. In addition to the weight of the trusses, floor and track, and to the strains thus deduced, must be added the effect due to a concentrated weight of 30,000 pounds on each track, moved across the bridge. The strains upon the entire floor system will be computed for a moving load of 6,000 pounds per foot of tract." Also, Mr. George H. Pegram, M. Am. Soc. C. E., in the Transactions for June, 1886, called attention to such a method, and in his paper gave some interesting comparisons covering spans as high as 400 feet.

To verify Mr. Waddell's Table of Equivalent Uniformly Distributed Live Loads, given on page 8 of his paper, I submit herewith Table No. 1, which I computed in February, 1884, and which is for a consolidation engine and tender weighing 88 tons in 54 feet. The loading and spacing for this engine are given on Plate XXII. This is very nearly like Mr. Cooper's Class A engine, shown on page 6 of Mr. Waddell's paper.

TABLE No. 1.

TABLE OF ACTUAL MAXIMA MOMENTS, End Shears and Cross-girder Loads for 88-Ton Consolidation Engine, and uniformly distributed loads equivalent thereto.

Eighty-eight-Ton Consolidation Engine and Tender, 54 feet long, out to out.

	Max. Moments.			End Shears.			Cross-girder Loads.		
Span in feet	Actual Max. Moment. Foot-tons.		Equivalent load per linear foot of track Pounds.	Actual End Shear Tons.		Equivalent load per linear foot of track. Pounds.	Actual Max. load on Cross-girder. Tons.		Equivalent load per linear foot of track. Pounds.
1	3.0	Case I.	48 000	12.0	Case I.	48 000	12.0	Case I.	24 000
2	6.0		24 000	12.0		24 000	12.0		12 000
3	9.0		16 000	12.0		16 000	12.0		8 000
4	12.0		12 000	12.0		12 000	12.0		6 000
5	15.0		9 600	13.2	Case II.	10 560	14.4	Case III.	5 777
6	18 0		8 000	15.0		10 000	18.0		6 000
7	21.0		6 857	16.3		9 308	20.6		5 877
8	24.8	Case II.	6 199	17.3		8 650	22.5		5 625
9	30.4		6 000	18.0	Case III.	8 000	24.0	Case IV.	5 333
10	36 0		5 766	19.8		7 920	26.4		5 280
11	45.0	Case III.	5 950	21.3		7 734	28.4		5 156
12	54.0		6 000	22 5		7 500	30.0		5 000
13	63.0		5 964	23.5		7 242	31.7	Case V.	4 875
14	72.0		5 877	24.9	Case IV.	7 104	33.4		4 776
15	81.0		5 760	26.4		7 040	34.9		4 659
16	90.0		5 625	27.7		6 939	36.2		4 530
17	99.6	Case IV.	5 512	28.9		6 810	37.4		4 412
18	111.4		5 500	30.0		6 667	38.4		4 271
19	123.2		5 460	30 9		6 516	39.4		4 144
20	135.0		5 400	31.8		6 360	40.8	Case VII.	4 080
21	146.9		5 330	32.6		6 204	42.3		4 027
22	158.8		5 248	33.5	Case V.	6 084	43.6		3 967
23	170.6		5 162	34.4		5 990	44.9		3 902
24	182.5		5 070	35.3		5 888	46.0		3 833
25	194.4		4 977	36.2		5 786	47.4	Case VIII.	3 789
26	206.3		4 884	36.9		5 680	48.9		3 763
27	220.0	Case V.	4 828	37.6		5 574	50.4		3 731
28	234.0		4 776	38.3		5 470	51.7		3 694
29	248.0		4 716	38.9		5 366			
30	262.0		4 658	39.7	Case VI.	5 298			
31	276.0		4 592	40.5		5 228			
32	290.0		4 532	41.2		5 156			
33	304.0		4 466	41.9		5 084			
34	318.0		4 400	42.6		5 010			
35	332.0		4 356	43.4	Case VII.	4 963			
36	346.0	Case VI.	4 272	44.2		4 913			
37	362 7		4 238	45.0		4 862			
38	376.6		4 172	45.7		4 809			
39	392.6		4 130	46.4		4 755			
40	408.5		5 065	47.2		4 720			

In Table No. 2 I also give similar data for a heavy passenger engine, to such span lengths, beyond which the results would be less than those given for the 88-ton consolidation engine in Table No. 1.

TABLE No. 2.

TABLE OF ACTUAL MAXIMUM MOMENTS, End Shears and Cross-girder Loads for 100-ton Fast Passenger Engine, and uniformly distributed loads equivalent thereto.

One hundred-ton Fast Passenger Engine and Tender, 54 feet long, out to out.

Span in Feet.	Max. Moments.			End Shears.			Cross-girder Loads.		
	Actual Max. Moments. Foot-tons.		Equivalent load per linear foot of track, Pounds.	Actual End Shears. Tons.		Equivalent load per linear foot of track. Pounds.	Actual Max. Load on Cross-girders.		Equivalent Load per linear foot of track. Pounds.
1	5.0	Case I.	80 000	20.0	Case I.	80 000	20.0	Case I.	40 000
2	10.0		40 000	20.0		40 000	20.0		20 000
3	15.0		26 667	20.0		26 667	20.0		13 333
4	20.0		20 000	20.0		20 000	20.0		10 000
5	25.0		16 000	20.0		16 000	20.0		8 000
6	30.0		13 333	20.0		13 333	20.0		6 667
7	35.0		11 430	20.0		11 430	....		....
8	40.0		10 000	20.0		10 000	....		....
9	45.0		8 888	22.2	Case II.	9 876	....		....
10	50.0		8 000	24.0		9 600	....		....
11	55.0		7 272	25.5		9 258	....		....
12	60.0		6 666	26.7		8 890	....		....
13	65.0		6 154	27.7		8 520	....		....
14	....		....	28.6		8 163	....		....
15	....		....	29.3		7 822	....		....
16	....		....	30.0		7 500	....		....
17	....		....	31.2	Case III.	7 336	....		....
18	....		....	32.2		7 160	....		....
19	....		....	33.1		6 972	....		....
20	....		....	34.0		6 800	....		....
21	....		....	34.8		6 620	....		....

This heavy passenger engine weighs, with its tender, 100 tons in 54 feet, as follows:

Two pairs of truck wheels at 10 tons.......... = 20 tons.
Two pairs of drivers at 20 tons............... = 40 "
Four pairs of tender wheels at 10 tons....... = 40 "

Total engine and tender.............. = 100 "

The spacing of the wheel loads is:

Pilot to first pair of truck wheels............. = 5′ 0″
Truck wheel base............................. = 7′ 6″
Rear truck wheel to leading driver............ = 8′ 0″
Driving wheel base.......................... = 8′ 0″
Rear driver to first pair of tender wheels........ = 8′ 0″
Tender wheel base. 3 at 5′ 0″................ = 15′ 0″
Rear tender wheel to end..................... = 2′ 6″

Total length of engine and tender........ = 54′ 0″

PLATE XXII
TRANS. AM. SOC. CIV. ENG'RS.
VOL. XXVI. No. 522
BLAND ON
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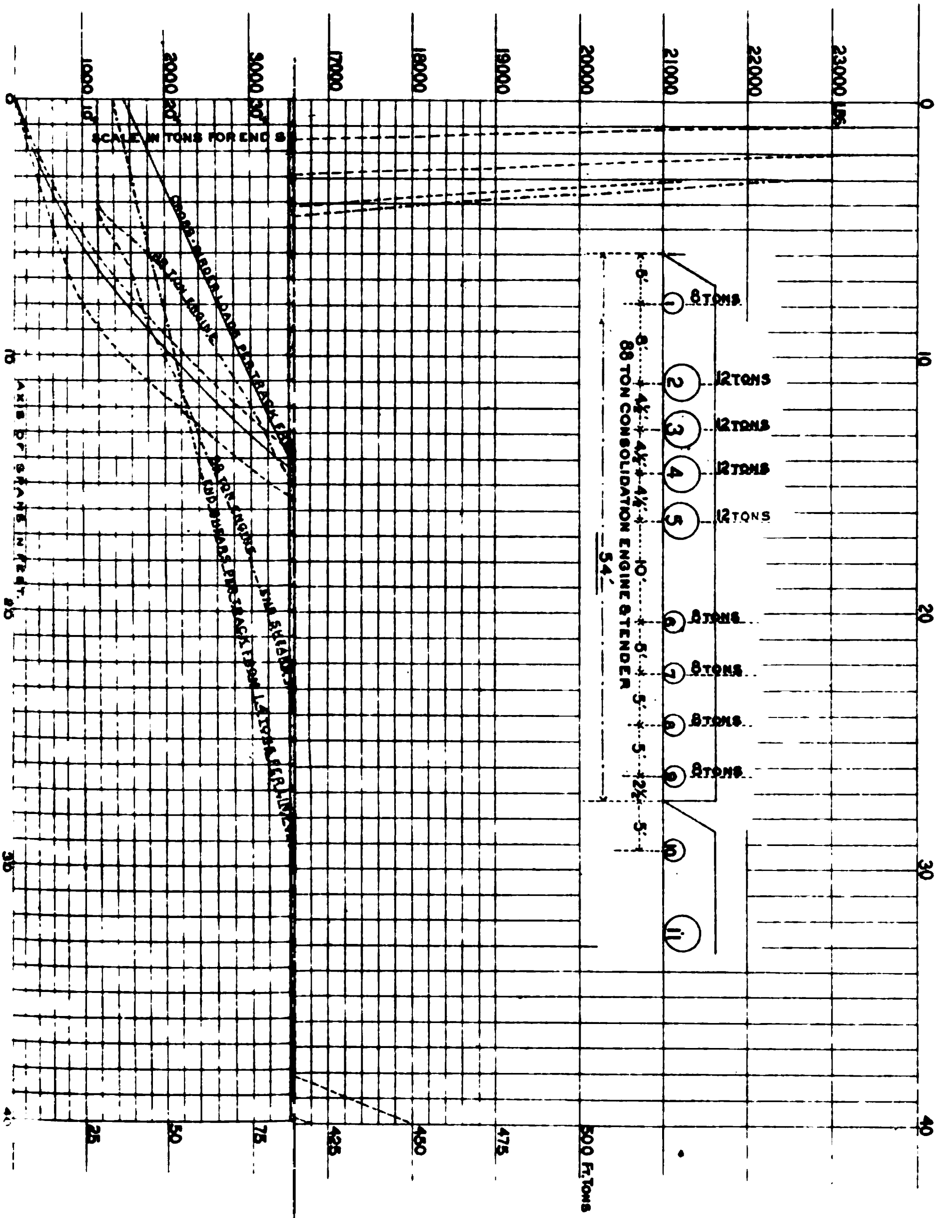

Combining Tables Nos. 1 and 2, in Table No. 3 is given the maximum bending moments for spans up to 40 feet, due either to a 100-ton passenger engine or 88-ton consolidation engine, whichever is the greater.

TABLE No. 3.

TABLE OF MAXIMA BENDING MOMENTS, due to 88-ton Consolidation or 100-ton Passenger Engine, whichever the greater, and equivalent uniformly distributed load per linear foot, corresponding to 2,800 pounds per foot + 28,000 pounds.

Span in Feet.	Case Number.	Critical Load.	Distance from center of span to the critical load. Feet.	Actual Maximum Moments per track. Foot-tons.	Equivalent uniformly distributed load per linear foot of track. Pounds.	Equivalent uniformly distributed load corresponding to 2 800 pounds per foot. + 28 000 pounds.
1	H. P. I.	P_3 or P_4	0	5 0	80 000	58 800
2	"	"	0	10.0	40 000	30 800
3	"	"	0	15 0	26 667	21 467
4	"	"	0	20.0	20 000	16 800
5	"	"	0	25.0	16 000	14 000
6	"	"	0	30.0	13 333	12 133
7	"	"	0	35.0	11 430	10 800
8	"	"	0	40.0	10 000	9 800
9	"	"	0	45.0	8 888	9 022
10	"	"	0	50.0	8 000	8 400
11	"	"	0	55.0	7 272	7 891
12	"	"	0	60.0	6 666	7 467
13	"	"	0	65.0	6 154	7 107
14	Cons. III.	"	0	72.0	5 877	6 800
15	"	"	0	81.0	5 760	6 533
16	"	"	0	90.0	5 625	6 300
17	Cons. IV.	P_3	1.125 left.	99.6	5 512	6 094
18	"	"	"	111.4	5 500	5 911
19	"	"	"	123.2	5 460	5 747
20	"	"	"	135.0	5 400	5 600
21	"	"	"	146.9	5 330	5 466
22	"	"	"	158.8	5 248	5 345
23	"	"	"	170.6	5 160	5 235
24	"	"	"	182 5	5 070	5 133
25	"	"	"	194 4	4 977	5 040
26	"	"	"	208 3	4 884	4 954
27	Cons. V.	"	0.071 left.	220.0	4 828	4 874
28	"	"	"	234.0	4 776	4 800
29	"	"	"	248.0	4 716	4 731
30	"	"	"	262.0	4 658	4 667
31	"	"	"	276.0	4 592	4 606
32	"	"	"	290.0	4 532	4 550
33	"	"	"	304.0	4 466	4 497
34	"	"	"	318.0	4 400	4 447
35	"	"	"	332.0	4 356	4 400
36	"	"	"	346.0	4 272	4 355
37	Cons. VI.	"	1.25 left.	362 7	4 238	4 313
38	"	"	"	376.6	4 170	4 274
39	"	"	"	392.6	4 130	4 236
40	"	"	"	408.5	4 085	4 200

On Plate XXII. is represented the variation in the maxima effects due to the 88-ton consolidation engine, and likewise is shown how the results of using a loading of 2,800 pounds per linear foot, plus a concentrated weight of 28,000 pounds, compare with those from the actual engine. Mr. George P. Bland, M. Am. Soc. C. E., to whom I showed the foregoing tables

in the spring of 1885, suggested the use of a uniform load in connection with a concentrated weight, to be practically equivalent in all respects to the maxima effects got by considering the wheel loading. He plotted the results from the tables on a diagram, and decided (I think) on 3,000 pounds per linear foot, plus 24,000 pounds, as well fitting the actual curves. I have frequently tested this suggested loading by comparison with the results from wheel concentrations, and in a wide range of spans have always found it gave exceedingly close approximations.

I may add that the Tables Nos. 1, 2 and 3 were computed from the expression—

$$M_0 = \frac{\Sigma . P}{4}\left(1 + \left[\frac{\Sigma' . Pd}{\Sigma . P}\right] . \frac{1}{l} - 2 . \frac{\Sigma . Pd}{\Sigma . P}\right)$$

where **M_0 = max. bending moment.**

$\Sigma . P$ = sum of loads on the span l.

$\Sigma' . Pd$ = summation of the moments of the loads on the span around the critical load as origin, regard being had to sign.

$\Sigma . Pd$ = summation of the moments of the loads on the span around the critical load as origin, no regard being had to sign.

d = spacing of the wheel loads.

The critical load is the one under which the maximum bending moment occurs. For a further explanation of the above expression, see my paper, "A Method of Computing the Absolute Maximum Bending Moment on Stringers, etc.," published in "The Engineering News" for February 2d, 1884.

In Table No. 4 is given the maxima bending moments due to two Pennsylvania Railroad consolidation engines shown in its specification of 1887, and for comparison also is given the maxima center moments from the loadings of 3,000 pounds per linear foot plus 30,000 pounds, and from 3,200 pounds per linear foot plus 32,000 pounds. On Plate XXIII. there are plotted these results; also the maxima moments from the Pennsylvania Railroad passenger engine of specification of 1887. An examination of the following table and diagram will show the degree of approximation which is given by the two assumed loadings.

In Table No. 5 are given the maxima bending moments resulting from two typical consolidation engines somewhat heavier than the engines of the Pennsylvania Railroad specification of 1887. These engines (and tenders) each weigh 110 tons in 54 feet. The spacing is as shown on Plate XXII., and the loading as follows:

One pair of pony wheels at 10 tons........... = 10 tons.
Four pairs of drivers at 15 tons.............. = 60 "
Four pairs of tender wheels at 10 tons.......... = 40 "

Total engine and tender.................. = 110 "

PLATE XXIII.
TRANS. AM. SOC. CIV. ENG'RS.
VOL. XXVI. Nº 522.
BLAND ON
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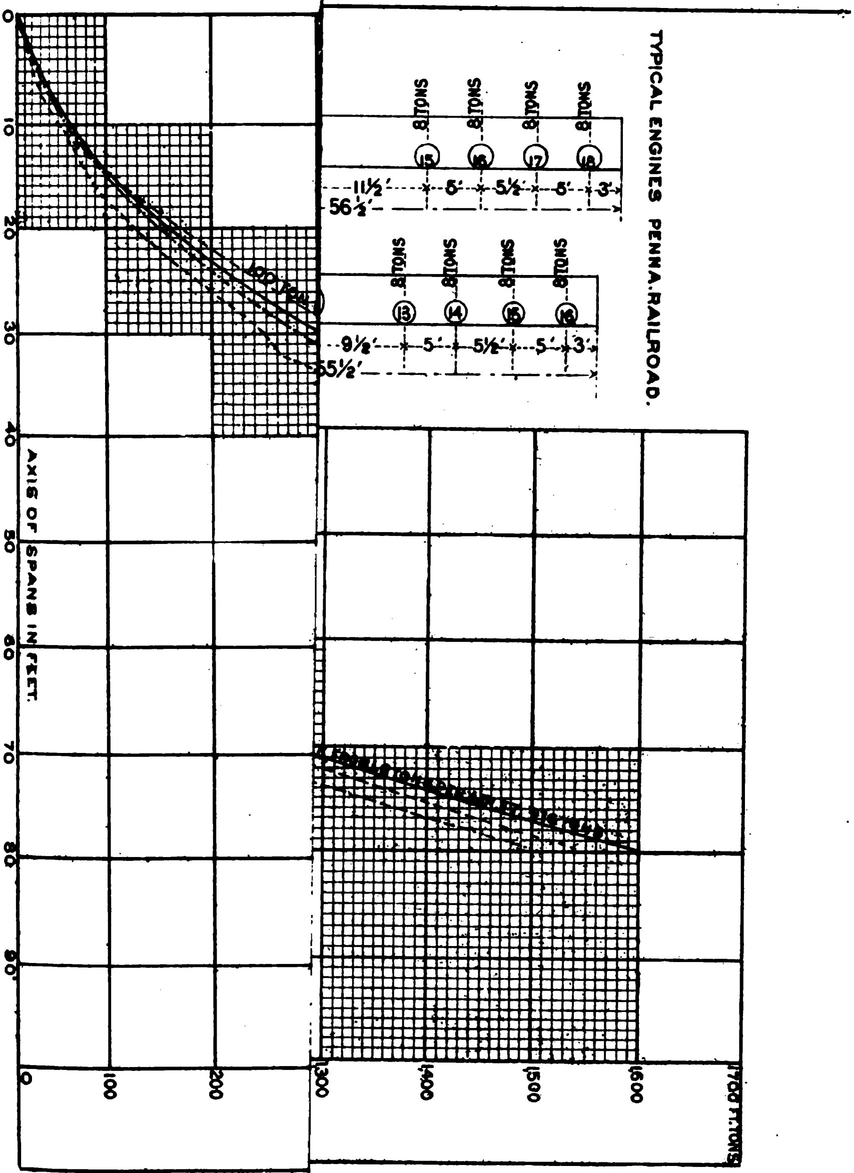

TABLE No. 4.

TABLE OF ACTUAL MAXIMA MOMENTS due to two typical Consolidation Engines—Pennsylvania Railroad Specifications of 1887. Also the Maxima Center Moments from 3,000 pounds per linear foot + 30,000 pounds, and from 3,200 pounds per linear foot + 32,000 pounds.

Span in Feet.	Case Number.	Critical Load.	Distance from center of span to the critical load. Feet.	Actual Maxima Moments in foot-tons per track.	Max. Center Moments due to 3 000 pounds per linear foot + 30 000 pounds. Foot-tons.	Max. Center Moments due to 3 200 pounds per linear foot + 32 000 pounds. Foot-tons.
1	I.	Any driver.	0	3.75	3 94	4.2
2	"	"	0	7.50	8.25	8.8
3	"	"	0	11.25	12.94	13.8
4	"	"	0	15.00	18.00	19.2
5	"	"	0	18.75	23 44	25.0
6	"	"	0	22.50	29.25	31.2
7	"	"	0	26.25	35.44	37.8
8	II.	P_3	1.125 left.	31.00	42.00	44.8
9	"	"	"	37.97	48.94	52.2
10	"	"	"	45.05	56 25	60.0
11	III.	"	0	56.25	63.94	68.2
12	"	"	0	67 50	72.00	76.8
13	"	"	0	78.50	80.54	85.8
14	"	"	0	90 00	89.25	95.2
15	"	"	0	101.25	98.44	105.0
16	"	"	0	112.50	108.00	115.2
17	IV.	"	1.125 left.	124.47	117.94	125.8
18	"	"	"	139.22	128.25	136.8
19	"	"	"	154.00	138.94	148 2
20	"	"	"	168.80	150.00	160.0
21	"	"	"	183.62	161.44	172 2
22	"	"	"	198.45	173.25	184.8
23	"	"	"	213 30	185.44	197.8
24	"	"	"	228.16	198.00	211.2
25	"	"	"	243.04	210.94	225.0
26	"	"	"	257.92	224.25	239.2
27	V.	"	0.26 left.	274.17	237.94	253.8
28	"	"	"	291.16	252.00	268.8
29	"	"	"	308.16	267.44	284.2
30	"	"	"	325.16	281.25	300.0
31	"	"	"	342.15	296.44	316.2
32	"	"	"	359.15	312 00	332.8
33	"	"	"	376.14	327.94	349 8
34	"	"	"	393.14	344 25	367.2
35	"	"	"	410.14	360.94	385.0
36	"	"	"	427.13	378.00	403.2
37	"	"	"	444.13	....	421.8
38	"	"	"	461.12	413.15	440.8
39	"	"	"	478.12	....	460.2
40	VI.	P_{12}	1.31 left.	496.26	450.00	480.0
41	"	"	"	515.19	....	500.2
42	"	"	"	534.11	488.25	520.8
43	VII.	"	0.21 left.	554.11	....	541.8
44	"	"	"	575.10	528.00	563.2
45	"	"	"	596.10	....	585.0
46	"	"	"	617.10	568.25	607.2
47	"	"	"	638.10	....	629.8
48	"	"	"	659.10	612.00	652.8
49	VIII.	"	1.30 left.	679.19	....	676.2
50	"	"	"	702.12	656.25	700.0
51	"	"	"	725.06	....	724.2
52	"	"	"	748 00	702.00	748.8
53	"	"	"	770.94	....	773.8

TABLE No. 4—(Continued).

Span in Feet.	Case Number.	Critical Load.	Distance from center of span to the critical load. Feet.	Actual Maxima Moments in foot-tons per track.	Max. Center Moments due to 3 000 pounds per linear foot + 30 000 pounds. Foot-tons.	Max. Center Moments due to 3 200 pounds per linear foot + 32 000 pounds. Foot-tons.
54	IX.	P_{12}	0.18 left.	797.06	749.25	799.2
55	"	"	"	822.06	....	825.0
56	"	"	"	847.05	798.00	851.2
57	"	"	"	872.05	....	877.8
58	X.	"	1.31 left.	920.94	847.25	904.8
59	"	"	"	946.94	....	932.2
60	"	"	"	973.89	900.00	960.0
61	"	"	"	1 000.38	....	988.2
62	"	"	"	1 026.89	953.25	1 016.8
63	"	"	"	1 053.41	....	1 045.8
64	"	"	"	1 071.00	1 008.00	1 075.2
65	XI.	P_{13}	0.21 left.	1 082.07	....	1 105.0
66	"	"	"	1 111.07	1 064.25	1 135.2
67	"	"	"	1 140.07	....	1 165.8
68	"	"	"	1 169.06	1 122.00	1 196.8
69	"	"	"	1 198.06	....	1 228.2
70	XII. (a)	P_{12}	1.30 left.	1 228.13	1 181.25	1 260.0
71	"	"	"	1 259.08	....	1 292.2
72	"	"	"	1 290 04	1 242.00	1 324.8
73	"	"	"	1 321.00	....	1 357.8
74	"	"	"	1 351.96	1 304 25	1 391.2
75	XII. (b)	P_{13}	0.96 right.	1 381.60	....	1 425.0
76	XIII.	"	0.99 left.	1 414.48	1 368.00	1 459.2
77	"	"	"	1 448.83	....	1 493.8
78	"	"	"	1 483.18	1 433.25	1 528.8
79	"	"	"	1 517.52	....	1 564.2
80	"	"	"	1 551.85	1 500.00	1 600.0

TABLE No. 5.

TABLE OF ACTUAL MAXIMA MOMENTS due to two Consolidation Engines and Tenders, each 110 tons, in 54 feet of total length. Showing also Maxima Center Moments due to 3,400 pounds per linear foot of track + 34,000 pounds concentrated.

Span in Feet.	Case Number.	Critical Load.	Distance from center of span to the critical load. Feet.	Actual Maxima Moments in foot-tons per track.	Maxima Center Moments due to 3 400 pounds per linear foot + 34 000 pounds. Foot-tons.
8	II.	P_3	1.125 left	31.0	47.6
14	III.	P_3	0	90.0	100.9
22	IV.	P_3	1.125 left	198.4	195.3
30	V.	P_3	0.143 left	327 6	318.7
38	VI.	P_3	1.25	470.8	468.4
46	VII.	P_4	0 388 left	645.1	645.1
52	IX.	P_{12}	0.09 right	792.6	795.6
62	X.	P_{13}	0.135 left	1 085.1	1 080.3
70	XI.	P_{13}	1.175 left	1 341.9	1 338.6
78	XIII.	P_{13}	0.541 left	1 649.7	1 624.3

The Table No. 5 shows how closely the maxima center moments from 3,400 pounds per linear foot, plus 34,000 pounds, coincide with the actual maxima moments. An examination of the tables and diagrams already mentioned will, I think, show the validity of Mr. Waddell's claims, and also indicate that a uniform load per linear foot plus a concentrated weight covers the case as well. This latter is also applicable to the computation of stresses in framed structures, giving a slight excess above the actual stresses in the counters and central panels of web members, a very excellent place, by the way, to have a surplus of metal.

Taking the loading to be $p + Q$, where $p =$ uniform load per linear foot, $Q =$ concentrated weight. Then for girder spans, where p can act continuously:

In flanges.—The maximum moment at any point x from the right abutment occurs where the span is fully covered with p per linear foot, and Q acting at the point x.

$$\text{Thus } M_x = \frac{px}{2}(l - x) + \frac{Q \cdot x}{l}(l - x).$$

When $x = \frac{l}{2}$, that is, when Q is at center of span, the greatest maximum movement occurs, and is—

$$M_o = \frac{pl^2}{8} + \frac{Ql}{4}.$$

Web.—The maximum shear at any point x from the right abutment occurs when p extends from o to x, and Q is at x.

$$\text{Thus } F_x = \frac{px^2}{2l} + \frac{Qx}{l}.$$

When $x = l$, the greatest maximum shear occurs, and is—

$$F_o = \frac{pl}{2} + Q.$$

Cross Girders.—The maximum load on a cross girder is given by $R = pl + Q$.

For girders where p acts discontinuously, or for truss bridges, the same principles hold good, using, however, the panel load $P = \frac{pl}{n}$ (where n is the number of panels) in connection with Q. The maximum at any panel point for the chords, is when the span is fully covered with p at every panel point, and Q at the panel point in question; and the greatest maximum moment occurs when Q is at the center of the span. The maximum shear in any panel x from the right abutment, is when each panel point to the right of x is loaded with p, and there is a load Q at the first panel point to right of x. It will be seen that the loading $p + Q$ conforms fairly closely to the results derived by using wheel concentrations, and where there is divergence it is due to some singularity in the wheel spacing or to peculiar relation between it and the panel length; or, again, to ratio between tender wheel loads and those on drivers, which ratio is usually two-thirds. The uniformly distributed load equivalent to the moment from the engine, M_o is

$$p'' = \frac{8\,M_o}{l^2},$$

in which the assumption is made that the engine maximum is at the center of the span. As a matter of fact, it is not always so, but still it never deviates much therefrom. (See Table No. 4.) The uniformly distributed load equivalent to the loading $p + Q$ is—

$$p'' = p + \frac{2Q}{l} = \text{also } \frac{8M_0}{l^2}.$$

Neither the maxima center moments $\frac{p''l^2}{8}$ nor $\frac{pl^2}{8} + \frac{Ql}{4}$ vary much from the engine moment M_0, and any ordinary variation is inconsiderable in view of the fact that the assumed static wheel loads, particularly the driver loads, are so subject to local changes—such changes as those caused by the centrifugal action of the driver counterweights, varying according to speed and to kind of engine, by the oscillations due to non-balance of engine on its springs, and by the variations in static load on drivers from a rough track or low joint.

Calculating stresses from wheel loadings tends to make the computer feel more than a warrantable confidence in his results, as being the true stresses in the several members. They are, indeed, true if the loads would remain static, which they do not. If allowance for impact, etc., were on the same basis of certainty as the static stresses from wheel loading, there would be no great fault to find; but methods for making such allowances are crude and seem insoluble in exactness. Nor would there be any objection to the use of wheel loading, despite the time wasted in preliminary designs such as Mr. Waddell speaks of, if in the end, in the results attained, closer accordance with the real and true stresses in the structure were obtained. It seems to me that the alternatives suggested, so closely in accordance with the wheel load results when statically considered, are (their simplicity and ease of application being fully weighed) fitting substitutes for the method now in vogue, and especially when no two specifications are alike as regards their typical engines, the differences frequently being just enough to make them unlike.

I think the use of a uniform load per linear foot, plus a concentrated weight, easier of application than that of a uniformly distributed load equivalent to the engine maxima moments. In the former the calculations are exceedingly simple and direct; in the latter, one has to have his memorandum book or his diagram of moments always at hand, so as to get the necessary equivalent uniformly distributed load, varying, as it does, for every span for even the same engine.

Regarding another point which Mr. Waddell makes—the examination of stress sheets tendered railroad companies in competitive bidding—if the scheme of $p + Q$ be used, every sheet could be tested by the one standard; whereas, now, "every man has his doctrine," though there is an absolutely mathematical, correct way of getting the static stresses due to wheel loading, which is neither troublesome nor tedious. I may say on such score, I have no very great fault to find with the present wheel concentration requirements. However, in the former method, the time is shortened alike to the designer and to the railroad company's engineer in comparing the several designs.

I would welcome the adoption of a specification in which, like Mr. Bouscaren's specifications of 1887, the live load requirements were simply stated by giving the values of p and Q, which corresponded broadly to the rolling stock which governed, or would in time govern, the bridge work on the line. I admit the great value which I think the wheel load requirements have been to us. The consideration of the actual thing which crosses our bridges has turned attention to just what that thing is, and we have realized in a way never before attained, to what local variations of loading an engine is subject, and some insight into the causes of such variations; and though no exact means is at hand to determine the true dynamic stresses resulting from these variations in wheel loading, this very uncertainty paves the way for other and quicker methods of getting the static stresses, to which we can (as we do now) make allowances for impact, etc., either by percentages to the apparent (static) stresses, or by a diminution of the working stresses, and attain results equally worthy of confidence.

As Mr. Waddell remarks, "All assumed loads for computing stresses in bridges are merely typical," and it is the provoking differences in these wheel concentrations for practically the same class of bridge which makes it especially hard on the engineer of a bridge company, whose daily duties are so increased by having to furnish with his bid a stress sheet complete —any minor inaccuracies in which throw doubt on his company's integrity or capacity to undertake the work, and makes it easier to give the work to the bridge company, which, as the author states, may have the "inside track."

Mr. Waddell also objects to the "added insult" of the computations being required to cover two different types of engines, and in some cases three. Such a demand is necessary when wheel loading is used, for the heavier concentrations on the drivers of an eight-wheel engine, even though farther apart, affect small spans. An example of this can be seen by inspecting Tables Nos. 2 and 3, where the heavy passenger engine governs the flange stresses in spans up to 13 feet, the end shears up to 20 feet, and cross-girder loads to 6 feet. This last is perhaps infrequent, and the increase in end shears beyond 16 feet is inconsiderable. It may be remarked, however, that the Pennsylvania Railroad use 8 feet panels in their through plate girder spans. The use of the loading p + Q covers well all these divergences.

As to "The Proper Live Load for Modern Bridge Specifications." Increase in engine weight and car capacity has been steadily going on since Mr. Cooper wrote his first specification, and the limit is not yet. Car capacity has steadily grown from the 40,000 pounds of a few years ago to the very ordinary 60,000 pounds of to-day. Engine weight, which ten to twelve years ago was for heavy consolidation engines, 95,700 pounds, 82,700 pounds of which was on the drivers, has increased to 114,600 pounds, 100,600 pounds of which is on the drivers, an increase of 21½ per cent. on drivers, or 20 per cent. increase in weight of the whole engine.

Class C passenger engine of Pennsylvania Railroad weighed 81,800 pounds; Class K, of the same line, weighs 96,700 pounds, and Class P weighs 100,600 pounds; roughly an increase of weight in the later types of 20 per cent. Excluding such peculiar types as the El Gubernador of Central Pacific, having 121,600 pounds on ten drivers, and the Baldwin Decapod of 128,000 pounds, on ten drivers; and, later, the engines working the St. Clair Tunnel, Grand Trunk Railway, having 180,000 pounds on ten drivers, in a space of 18¼ feet, all of which were designed for special work in comparatively limited localities; we are justified, I think, in saying that the increased requirements of railway traffic of the past ten years have demanded about 25 per cent. increase in the weight of the engines. In other words, the driver loads in engines of the consolidation type have increased from 20,000 to 25,000 pounds per pair.

As regards the cars, while the capacity has increased 50 per cent., the weight has increased but about 20 per cent., or the total loading but 40 per cent. The present stock weighs loaded about 2,500 pounds per linear foot of track, the length being about 34 feet, and the wheel base about 27 feet; and allowing for overloading, these cars would weigh probably close to 2,700 pounds per foot of track.

Roughly speaking, then, the past ten years has witnessed an increase in engine weight of 25 per cent. and an increase in car weight of 50 per cent., the former affecting materially all floor systems and spans say 100 feet and under, and the latter affecting all other spans to at least 25 per cent., since the train load on lines having this kind of traffic was formerly rarely assumed less than 1 gross ton per foot. On some lines the increased weight of train load would cause no excess, since even ten years ago the rolling load was assumed at 3,000 pounds per linear foot.

Tables Nos. 6, 7 and 8 give data for rolling stock in actual use at present in Colorado and Utah, and in Tables Nos. 7 and 8 the Colorado engines are compared with Pennsylvania Railroad engines and with English engines doing same class of work. Inspecting Table No. 7, and bearing in mind that Class R is, I think, the heaviest consolidation type now in use on that line, it is seen that the Denver and Rio Grande Class 112 is but 2,100 pounds lighter, or engine and tender together 5 per cent. heavier than Class R; that the Colorado Midland Consolidation engine has 13 per cent. more weight on the drivers, the engine and tender together being 20 per cent. heavier than Class R; however, it carries $33\frac{1}{3}$ per cent. more water and 100 per cent. more coal, operating as it does on a 3 per cent. line.

TABLE No. 6.

STANDARD FREIGHT STOCK IN ACTUAL USE ON DENVER AND RIO GRANDE RAILROAD.

	Gondola Coal Car.	Hopper Bottom Coal Car.	Low Flat Car—Continuous Draw Bar.	Box Car.	Stock Car.
Length out to out of bull-nose.	34′ 6″	30′ 6″	34′ 8½″	34′ 6″	34′ 6″
Length over end sills............	32′ 0″	28′ 0″	32′ 0″	32′ 0″	32′ 0″
Max width of car, out to out ..	9′ 8″	10′ 0″	9′ 2″	9′ 3″	9′ 3″
Number of trucks...............	2	2	2	2	2
Kind of truck	4-wheel	4-wheel	4-wheel	4-wheel	4-wheel
Wheel base of truck............	4′ 8″	4′ 8″	4′ 8″	4′ 8″	4′ 8″
Wheel base of car.........	27′ 3″	23′ 0″	27′ 3″	27′ 3″	27′ 3″
Weight of car....................	24 000	25 000	21 000	26 000	26 000
Capacity of car	60 000	60 000	60 000	60 000	60 000
Total weight of car and load...	84 000	85 000	81 000	86 000	86 000
Weight per linear foot of track.	2 435	2 785	2 335	2 495	2 495
Ratio $\frac{\text{weight}}{\text{capacity}}$	0.40	0.42	0.35	0.43	0.43
Ratio $\frac{\text{weight}}{\text{total weight}}$	0.28	0.29	0.26	0.30	0.30
Relative capacity to weight.....	1 to 2½	1 to $2\frac{4}{10}$	1 to $2\frac{9}{10}$	1 to $2\frac{3}{10}$	1 to $2\frac{3}{10}$

MEMORANDUM.—Allowing for overloading, 2 700 pounds per linear foot will cover the weight of train.

TABLE No. 7.

FREIGHT ENGINES IN ACTUAL USE IN 1891.

	Class R. Engine Consolidation, Penna. Railroad, 1886.	Class 112. Consolidation Engine, Denver and Rio Grande Railroad, 1888.	Colorado Midland, Consolidation Engine, 1888.	Class 133½. Consolidation Engine, Rio Grande Western Railway, 1891.	Freight Engine, Great Northern Railway, England.
Weight on pony truck...........	14 000	16 700	12 000	16 700	none.
Weight on eight drivers.........	100 600	95 800	114 000	98 300	90 160
Total weight of engine..........	114 600	112 500	126 000	115 000	90 160
Weight of tender loaded.........	57 800	68 000	82 000	68 000	58 800
Total weight of engine and tender........................	172 400	180 500	208 000	183 000	148 960
Rigid wheel base.................	13′ 10″	13′ 6″	14′ 6″	13′ 6″	17′ 7″
Engine wheel base................	21′ 9″	21′ 4″	22′ 0″	21′ 6″	17′ 7″
Tender wheel base...............	16′ 4″	16′ 0″	15′ 6″	15′ 10″	20′ 7″
Total wheel base of engine and tender........................	48′ 9″	48′ 4″	48′ 0″	48′ 4″	48′ 7″
Total length of engine and tender, out to out............	57′ 8″	about 58′ 6″	58′ 0″	60′ 0″	....
Water capacity of tank.........	3 000 gals.	....	4 000 gals.	3 200 gals.	....
Coal capacity of tender..........	8 000 lbs.	....	16 800 lbs.	15 680 lbs.	....
Diameter of drivers.............	50″	45″	51″	45″	
Cylinders........................	20″ x 24″	20″ x 24″	20″ x 26″ generally	20″ x 24″	19″ x 28″
Maximum grade...................	....	3%	3%	3.8%	
General grade....................	....	1 and 1½%	3%	1%	
Maximum curve...................	....	12°	16°	about 10°	

TABLE No. 8.

PASSENGER ENGINES IN ACTUAL USE IN 1891.

	Class P. Passenger Engine, Penna. Railroad.	Class 106, Passenger and Freight, Denver and Rio Grande Railroad, 1888.	Colorado Midland Railway Passenger Engine, 1888.	Rio Grande Western Railway Passenger Engine, 1891.	English Express Engine.
Kind of engine....................	8-wheel.	10-wheel.	10-wheel.	10-wheel.	6-wheel.
Number of drivers...............	4	6	6	6	2
Weight on trucks.................	40 850	26 300	21 850	....	....
Weight on drivers................	65 150	84 400	98 950	Practically the same as Denver and Rio Grande. Class 106.	34 000
Total weight of engine...........	106 000	106 700	120 800		85 000
Weight of tender, loaded........	60 000	68 000	82 000		....
Total weight of engine and tender........................	166 000	174 706	202 800		....
Rigid wheel base.................	7′ 9″	11′ 9″	12′ 0″		....
Engine wheel base................	22′ 7½″	23′ 0½″	22′ 6″		15′ 6″
Tender wheel base...............	15′ 4″	16′ 0″	15′ 0″		12′ 0″
Total wheel base of engine and tender........................	47′ 8″	47′ 3½″	48′ 9″		....
Total length of engine and tender, out to out............	56′ 2″	58′ 0″	56′ 9″		....
Water capacity of tank..........	3 000 gals.	....	4 000 gals.		2 400 gals.
Coal capacity of tender..........	12 000 lbs.	....	16 800 lbs.		....
Diameter of drivers..............	68″	54″	57″		84″
Cylinders........................	18½″ x 24″	18″ x 24″	19″ x 26″		17″ dia.

In Table No. 8 comparison is made of the eight-wheel Class P of the Pennsylvania Railroad with the ten-wheel engines in Colorado and Utah, these latter being used for all passenger service as well as for light freight trains. It will be noticed that the Colorado Midland ten-wheeler has 16,500 pounds on each driver.

Bridges of different capacities will, of course, be required, according to the varied positions of the lines, the kind and volume of the traffic, actual or probable, and the gradients and alignments, the last two governing the class of locomotives to be used. Mr. Cooper's four diagrams of consolidation engine loading seem to me to cover broadly the several classes of railways operating in the United States. I agree, however, with Mr. Waddell in his plea for more uniformity and greater simplicity in the spacing of the loads. For consolidation engines all the spacing could, I think, be multiples of 5 feet. I would exclude the mogul engine and its 2,000-pound train load, and assume the train loads for the heavy grade, extra Class A, Class A and Class B to be respectively 4,000, 3,400, 2,800, and 2,500 pounds per linear foot.

Retaining Mr. Cooper's notation, on the system of calculation of $p + Q$, the scheme could be written as follows, and which I think would give practically the same class of bridge.

Heavy Grade	$p + Q = 4{,}000$	pounds	$+ 40{,}000$	pounds.
Extra Class A	$p + Q = 3{,}400$	"	$+ 34{,}000$	"
Class A	$p + Q = 2{,}800$	"	$+ 28{,}000$	"
Class B	$p + Q = 2{,}500$	"	$+ 25{,}000$	"

These would correspond pretty well with the following engines:

FIRST.—Heavy Grade Consolidation Engines and 4,000-pound train.

On each truck and tender axle	20,000	pounds.
On each driver axle	40,000	"
Total weight engine and tender	260,000	"

SECOND.—Extra Class A, Consolidation Engines and 3,400-pound train.

On each truck and tender axle	20,000	pounds.
On each driver axle	30,000	"
Total weight engine and tender	220,000	"

THIRD.—Class A, Consolidation Engines and 2,800-pound train.

On each truck and tender axle	16,000	pounds.
On each driver axle	24,000	"
Total weight engine and tender	176,000	"

FOURTH.—Class B, Consolidation Engines and 2,500-pound train.

On each truck and tender axle	14,000	pounds.
On each driver axle	22,000	"
Total weight engine and tender	158,000	"

All the foregoing engines to have the following spacing:

Pilot to truck	5′ 0″
Truck to leading driver	10′ 0″
Three driver spaces at 5′ 0″	15′ 0″
Rear driver to first tender wheel	10′ 0″
Three tender spaces at 5′ 0″	15′ 0″
Rear tender wheel to end	5′ 0″
Length of engine and tender out to out =	60′ 0″

Table No. 9 gives the typical consolidation engines in use on the Denver and Rio Grande Railroad as compared with those of the Pennsylvania Railroad's specification of 1887.

TABLE NO. 9.

TYPICAL FREIGHT ENGINES used in Bridge Specifications on the Denver and Rio Grande Railroad and on the Pennsylvania Railroad.

	Typical Consolidation Engine of Pennsylvania Railroad. Specifications of 1887.	Typical Consolidation Engine, Denver and Rio Grande Railroad. Load Diagram No. 5, 1888.
Weight on pony trucks	16 000	20 000
Weight on each pair of drivers	30 000	30 000
Weight on four pairs of drivers	120 000	120 000
Total weight of engines	136 000	140 000
Weight on each tender axle	16 000	20 000
Total weight of tender	64 000	80 000
Total weight of engine and tender	200 000	220 000
Rigid wheel base	13′ 6″	13′ 6″
Engine wheel base	21′ 6″	21′ 6″
Tender wheel base	15′ 6″	15′ 0″
Total wheel base of engine and tender	48′ 6″	46′ 6″
Total length of engine and tender, out to out	56′ 6″	54′ 0″

While the assumed driver loads in each are the same, the tender loads of the former are necessarily greater, having to carry more coal and water. The Denver and Rio Grande engine and tender is just 10 per cent. heavier than the present requirements of the Pennsylvania Railroad. That this excess is justified is seen by reference to Table No. 7 of actual data, and moreover I think the chances for further increase in the weight of engines are greater on such lines as the Denver and Rio Grande than on the Pennsylvania Railroad, though in the matter of train load the reverse would be the case—the one operating a comparatively low grade line, the other a line having a maximum gradient of 3 per cent., and curves of 10 and 12 degrees. It should be mentioned, too, that the Colorado Midland consolidation engines (and tender) weighing only 8 per cent. less than the typical consolidation engines of the Denver and Rio Grande, for several months of this year ran over 75 miles of the Denver and Rio Grande tracks.

Considering the Tables Nos. 6, 7, 8, and 9, in which it is shown that the car stock of the Denver and Rio Grande Railroad is abreast of modern requirements, the actual consolidation engines in use slightly heavier than those of the Pennsylvania Railroad, and the typical consolidation engine necessarily 10 per cent. heavier, for reasons already given, than that of the latter line; the question arises: if the assumed engine loads are practically alike, should the bridges be designed with the same margin of strength? that is, should the same working stresses be used? My answer would be, bridges on the former line should be made fully up to the very best requirements of present practice, while those on the Pennsylvania Railroad and like lines should have a wider margin of strength than now obtains.

Excluding shifting engines at Denver, there are all told about seventy trains per twenty-four hours belonging to the Denver and Rio Grande tracks, whilst in the Philadelphia terminal of the Pennsylvania Railroad there are, perhaps, close to six hundred trains every twenty-four hours. Out well on the line of the Denver and Rio Grande there are possibly no more than twelve or fifteen trains per day, whilst on the Pennsylvania Railroad Division there are at least one hundred and fifty. To carry the comparisons farther away, at Clapham Junction, London, there is a train passing at an average of every fifty-four seconds from 7 A. M. to 10 P. M.; and at Cannon Street Bridge, London, thirty-five trains have been counted in as many minutes.

Our specifications, worthy the name, make differences in bridges, depending only on differences of assumed loading, the unit stresses used being the same; that is, all the bridges are to be first-class as regards dimensioning. The same assumed loading will give the same bridge, no matter where its location or on what kind of line. We make bridges presumably to last an unlimited time under an assumed loading, by using a factor of about three on a quantity beyond which an unlimited number of repetitions will not cause rupture, or else we use working stresses of about one-third the elastic limit, lowered in certain instances an arbitrary quantity to allow for impact, etc., and yet an increase in assumed loading of about 25 per cent. has seemed to cause signs of weakness to appear in bridges presumably so made. How this can be is hard to understand, unless our marginal factor of three involves in reality less margin than is supposed.

The Wöhler-Launhardt scheme was based on experiments on prepared test pieces, and on loads supposed to be gradually applied at intervals of something like fifteen seconds. It becomes a question to what extent suddenly applied loads would affect the ordinary statement of these experiments.

Kirkaldy found a reduction of about 20 per cent. in ultimate capacity, by suddenly applying a load, "without jerk"; but it is in some such way as "with jerk" that our live loads are applied. From some points of view it would seem that a rapidly passing train exerts less damaging effect on a bridge than were the speed less, especially if the track be good. Clearly our bridges will not last an unlimited time, and equally clear is it, if such be the case, that the amount of actual or probable traffic demands a place in bridge designing. On the line cited, a most exaggerated estimate of prospective traffic would not, in fifty years, reach one-fourth of that now on the Pennsylvania Railroad; and I think it likely, considering the grades, as now their engines are as heavy as the latter's, we can look for increase in weight sooner than on the Pennsylvania Railroad; still under the same loading one bridge is doing nearly ten times the work of the other.

I have examined a very fair number of bridges, and, on the basis of first-class working stresses, in some instances found them overstrained 12 to 20 per cent. when passed by the engines in use, a fact which should cause no uneasiness, considering the infrequency of the loading, and there being no evidences of weakness. Had these bridges been crossed by from one hundred to four hundred trains per day, the case would, in my judgment, be very different, though the unit stresses caused by every passage would, in each case, have been the same. In design, too, we figure for double headers, though their use is in small proportion to trains headed by one engine, except, of course, on certain heavy grades, where double headers are the rule.

A short time ago, in a Philadelphia newspaper, it was stated that a bridge over the Schuylkill River was being strengthened because it had grown "tired" under the passage of about 500 trains per day. As the cost of the repairs was put down at $25,000, and as being 12½ per cent. of the original cost of the bridge, I fancied the statement to be substantially true, though I write under correction. Here is a bridge designed by an eminent engineer, built by a most reputable bridge works, presumably proportioned for the heaviest engines of ten years ago, and on working stresses, if anything, lower than in general use, and at least no greater than 5 tons per square inch on lower chord and main diagonal bars.

The bridge is used principally for passenger and express traffic, for such are the trains which form the greater proportion of the five hundred stated. An increase in weight of 25 per cent. in engine and train over that for which it was designed would only raise the unit stress in tension to 6¼ tons per square inch, which is at least still under one-half the elastic limit, and yet report says the bridge is "fatigued." The same bridge under the same loads but of less frequent application of them would, I dare say, show no signs of weakness nor necessity of repair. As it is, does it not show the necessity of making bridges which bear such frequent passages of the load with a wider margin of strength than those, which, though under the same loading, are so situated as now to get but few applications of it, and to be never likely to get as many as five hundred daily, year in and year out? It shows, too, the best designed bridges do not have an unlimited life, as is the supposition in fixing the working unit.

The New York Elevated structures have required strengthening during the past few years; their engines, it seems, have been increased some 26 per cent. in weight, and the number of trains daily, multiplied enormously. Originally, no doubt, the bridges were well proportioned, with the design and workmanship at least up to the average standard of their day. If, under the originally assumed loads, the working stress was low enough to fit the supposition of unlimited life, would an increase of 26 per cent. in the load itself, raise the unit stresses to a limit where weakness was exhibited?

It seems highly probable that very frequent applications of such loading do cause dynamic stresses quite beyond what is supposed, and bridges at terminals and like places, passing hundreds of trains daily, some as often as one a minute for at least twelve hours per day, require a much greater margin of safety than is now given even under the usual assumption of unlimited life.

Regarding the structure mentioned in the discussions on "Inspectors and Bridge Work," "Transactions" for December, 1887, page 313, Mr. Cooper says: "There have been, however, no defects developed in these structures which cannot be clearly traced to faulty design, hasty workmanship, or want of appreciation of traffic demands; and not a bit of evidence can be found to show that the rapidity or number of trains have developed defects that would not in time have been produced under other conditions of the same loads. I do not believe that any number of applications of the loading will produce any more injury than a single loading upon a structure so proportioned that the actual strains shall never exceed the elastic capacity of that material."

Mr. Sloan (page 310) said, "The structures were designed by careful engineers, and built and erected by responsible bridge building firms"; he also says that "due to an increase in weight of engines from 17 to 19 and 21¼ tons, and, to keep the factor of safety within the limit prescribed by the Rapid Transit Commissioners, we have strengthened the floor beams on the Sixth Avenue pin-connected structures, and strengthened the Third Avenue girders by a double system of triangulation."

In view of Mr. Sloan's statement the question suggests itself, was the design, which, Mr. Cooper states, was faulty in respect of the judgment of to-day, considered so at the time of building? If the former, though there has been great progress in design during the past ten years, is there any finality about our present knowledge and practice? And as respects Mr. Cooper's statement regarding the action of stresses within the elastic limit, such is true, but the question arises: may not the dynamic stresses (repeated about one thousand times a day), induced on the structure, coupled with shock, etc., have been such that, in connection with 26 per cent. increase in weight of engines, the elastic limit has been nearly approached if not exceeded?

By repeated stress beyond the original elastic capacity, the limit may be "exalted," and experiment shows very much so; but it certainly renders the bar or structure less able to resist the frequently repeated applications of stresses, or, in other words, the capacity to endure work is very much lessened. Of course, if the engines were increased 26 per cent. in weight or thereabouts, and at the same time certain commissioners lowered the allowable working stresses, the required strengthening offers no subject for either comparison or criticism, nor any grounds for argument as to the necessity of a greater margin of strength in structures subjected to maxima loads as often as every minute or two.

Though the question may receive no answer from the Elevated Lines of New York, in the case of the Philadelphia bridge no State Commissioners have had any jurisdiction, the required strengthening being undoubtedly evident to the railroad officials and so ordered. It is rather curious to note that, in both instances, the structures are almost entirely under passenger traffic, though, without doubt, the Philadelphia bridge was designed for consolidation engines followed by a 3,000-pound train. In this connection it may not be amiss to mention "Cooper's Counter-rod," quoted by Prof Thurston. It had tenacity, 44,000 pounds per square inch; elastic limit, 36,000 pounds per square inch; fractured area = original area; elongation = none; fracture, crystalline facets, large, and as ductility may be deduced from elongation and contraction of area, the above is suggestive. It would likewise be interesting to consider, for example, what Prof. Thurston says on the "law of fatigue and the refreshment of metals."

INTENSITIES OF WORKING STRESSES.—Regarding Mr. Waddell's assumption "that in the near future the material for the metal portions of railway bridges will be exclusively steel," it may be remarked that the most important railroad in the country still refuses to use steel in its structures, even, I understand, to the exclusion of steel eyebars; and that a large line west of Pittsburgh, by implication, from reading its specification, contemplates the use of iron structures to the exclusion of steel. Until such railroads can be shown the "errors of their ways," I fear Mr. Waddell's "near future" will be somewhat remote.

As to the relation between statically applied loads and the same loads applied with different velocities, this, as Mr. Waddell says, is still practically unsolved, and though one of the most important points in the design of a bridge, there seems little unanimity of opinion amongst our best engineers regarding even the points of view from which to approach the subject. The Society has had the benefit of two different papers which, I think, are worthy of close attention, viz., Professor Robinson, M. Am. Soc. C. E., in "Transactions" for June, 1886, pp. 432 to 437, and the same on "Vibration in Bridges," in "Transactions" for February, 1887; and Mr. William H. Booth, M. Am. Soc. C. E., on the "Stresses in Bridges," in "Transactions" for April, 1889. These papers, though independent, overlap to some extent in their conclusions, especially those relating to the avoidance of a panel length, which is a multiple of the driver wheel circumference. This question, considering the variety of driver diameters on any one line, it seems almost impossible to consider in bridge design, or to allow a defined place in bridge specifications. On one important railroad, for example, the engines in use have driver diameters of 44, 50, 56, 62, 68, and 78 inches.

It will be readily granted, I suppose, that live loads produce effects intermediate between those due to static stresses and those due to shock from a body falling freely by gravity. Mr. Booth, in his paper referred to, apparently following this view, assesses the percentage for impact in any span by the ratio of the times occupied respectively by the body in falling freely by gravity through a height equal to the deflection, and by the time occupied in reaching the center of the span. For the deflection he assumes $\frac{1}{2400}$ of the span, which, he states, Prof. Robinson's observations show; this deflection is the static deflection due to live load, whereas, I think, it is the dynamic deflection due to live load which should enter the ratio, and this may be assumed as twice the former, or, say, $\frac{1}{1200}$ of the span. Using this in the equation for impact percentages, we get, $p = \frac{50}{35} \cdot \frac{v}{\sqrt{l}}$, which may be written approximately, $p = \frac{3}{2} \cdot \frac{v}{\sqrt{l}}$, where v = velocity of train in feet per second; l = the span in feet; p = impact percentage. The argument and reasoning leading to the foregoing equation are clearly given in Mr. Booth's interesting paper, to which reference is here made. In order to exhibit the variation in impact percentages for sundry spans and speeds, Table No. 10 is given, calculated from $p = \frac{3}{2} \cdot \frac{v}{\sqrt{l}}$, for velocities of 30, 40, 50, 60, 70, and 90 feet per second, corresponding to speeds of 20½, 27, 34, 41, 48, and 61½ miles per hour.

TABLE NO. 10.

IMPACT PERCENTAGES FROM P $\frac{3}{2} \cdot \frac{v}{\sqrt{l}}$

Span in Feet.	$v = 30$ $V = 20\frac{1}{2}$	$v = 40$ $V = 27$	$v = 50$ $V = 34$	$v = 60$ $V = 41$	$v = 70$ $V = 48$	$v = 90$ $V = 61\frac{1}{2}$
5	20.1	26.8	33.5	40.3	47.0	60.3
10	14.1	18.8	23.5	28.2	32.9	42.3
15	11.7	15.6	19.5	23.4	27.3	35.1
20	9.9	13.2	16.5	19.8	23.1	29.7
30	8.1	10.8	13.5	16.2	18.9	24.3
40	6.9	9.2	11.5	13.8	16.1	20.7
50	6.3	8.4	10.5	12.6	14.7	18.9
60	5.7	7.6	9.5	11.4	13.3	17.1
70	5.4	7.2	9.0	10.8	12.6	16.2
80	5.1	6.8	8.5	10.2	11.9	15.3
90	4.8	6.4	8.0	9.6	11.2	14.4
100	4.5	6.0	7.5	9.0	10.5	13.5
150	3.6	4.8	6.0	7.2	8.4	10.8
200	3.3	4.4	5.5	6.6	7.7	9.9
250	2.7	3.6	4.5	5.4	6.3	8.1

There is also to be considered the centrifugal force due to vertical non-balance of the counterweights on the drivers. I find that an average of 200 pounds per wheel acting at the crank pin center represents fairly closely the quantity to be considered. When the counterweight is "down," the dynamic augment to the wheel load is given by

$$P = \frac{W \cdot v^2}{g \cdot r} = .0031\ v^2.$$

where P = centrifugal force in tons due to the counterweight.
W = the above 200 pounds = $\frac{1}{10}$ ton.
v = velocity of crank pin in feet per second.
g = gravitation unit = 32.
r = radius of circle described by center of crank pin = generally 1 foot.

Assuming consolidation engines having 12,000 pounds on each driver of 44 inches diameter; ten-wheelers having 15,000 pounds on each driver of 54 inches diameter; and eight-wheel passenger engines having 16,000 pounds on each driver of 64 inches diameter; and further assuming two crank pin velocities in each case, viz., 20 and 30 feet per second, Table No. 11 is constructed, which shows the dynamic augment when the counterweight is "down" and its percentage of excess above the static load on the driver wheel. It is, of course, to be remembered that when the counterweights are "down" on one side of the engine they are horizontal on the other side, and on that side exert no vertical excess; also that when counterweights are "up," the static wheel load is decreased by the same amount as it was before augmented when counterweights were "down"; so the range or variation in the dynamic load of a wheel is double the dynamic augment. Further, the crank pin velocity is greater the less the diameter of the driver, so that small drivers at high speeds are the most damaging.

TABLE No. 11.

DYNAMIC AUGMENT to Driver Loads due to action of Counterweights, calculated from $P = .0031\ v^2$.

Kind of Engine.	Speed in Miles per Hour.	Velocity of Crank Pin in feet per second.	Dynamic Augment on each driver when counterweight is down. Tons.	Load on each driver. Tons.	Per cent. of excess above the static driver load.
Consolidation..........	25	20	1.24	6.0	20⅔
"	37½	30	2.79	6.0	46½
Ten-wheeler............	30½	20	1.24	7.5	16½
"	46	30	2.79	7.5	37¼
Eight-wheel pass.......	36⅓	20	1.24	8.0	15½
"	54½	30	2.79	8.0	35

If any one doubts the weight which considerations such as the foregoing should have in bridge design, let him ride on an engine for a few days. He will then appreciate in a practical way how the load is applied to a railway bridge—what blows the floor-system has to stand—the meaning of "plunging" and the engine "working hard"—how the weight carried by the engine springs is thrown now on this side, now on that—and what shocks are caused by a bad track or low joints; and if he recalls the fact that action and reaction are equal and opposite, his views of moving load may change. From considering a rapidly moving body of invariable distribution of loading gliding over an imaginary track without joints, he will remember all the above; and last, but not least, he will realize that the condition of the track leading to the bridge determines how the engine will be acting when it crosses, and perhaps conclude that next in importance to a stiff floor system, is a good track leading to and over it.

Considering the form cited by Mr. Waddell,

$$\text{Intensity} = \text{constant}\left(1 + \frac{\text{min. stress}}{\text{max. stress}}\right).$$

In this expression there is allowance both for the supposed effects of fatigue and for impact. Excluding impact, and allowing only for the effect of an unlimited number of repetitions of stress, the expression is commonly written:

$$\text{Intensity} = \text{constant}\left(1 + \tfrac{1}{2}\,.\,\frac{\text{min. stress}}{\text{max. stress}}\right).$$

Are not the above mere empirical modifications of Launhardt's formula, of which the general form he gave was

$$a = w\left(1 + \frac{t - w}{w}\,.\,\phi\right)$$

where

a = the ultimate strength of the member.

w = the stress which by an unlimited number of repetitions failed to break the bar, the bar after each repetition returning to an unstrained condition.

t = the ultimate capacity of the piece under one steady slow stress, viz., the static breaking weight.

Now, the value, $\frac{t - w}{w} = \frac{1}{2}$, gives $w = \frac{2}{3}\,t$; and the value, $\frac{t - w}{w} = 1$, gives $w = \frac{1}{2}\,t$. Thus the first expression considering ultimate strength is, $a = \frac{t}{2}\,(1 + \phi)$; and the second is, $a = \frac{2}{3}\,t\,(1 + \frac{1}{2}\,\phi.)$ For an all dead load both become $a = t$; and for an all live load the first becomes $a = \frac{t}{2}$, and the second becomes $a = \frac{2}{3}\,t$; whence the form,

$$\text{Intensity} = \text{constant}\left(1 + \frac{\text{min. stress}}{\text{max. stress}}\right)$$ agrees with the assumption that a member under an all live load repeatedly applied, is capable only of standing one-half of what it would were the load all dead and once applied, and, therefore, presumably includes impact. And the form,

$$\text{Intensity} = \text{constant}\left(1 + \frac{\text{min. stress}}{\text{max. stress}}\right)$$ agrees with the assumption that a member under an all live load when indefinitely applied is capable of standing but two-thirds of what it would were the load all dead and once applied, and therefore excludes impact, agreeing as it does with Launhardt's original expression.

The values given to t and w will, of course, vary as the member is a rolled bar, or of plates or shapes. If the constant be considered to represent w divided by a marginal factor, the result gives the working stress, and this marginal factor could change with due regard to the place and office of the member in the structure. The use, however, of Launhardt's formula or modifications of it to cover impact, has already received wide discussion, unnecessary to repeat. Paper No. 1882 of the Institute of Civil Engineers, by Weyrauch, goes well into the matter from various points of view. Also the subject was pretty well threshed out in the "Transactions" for June, 1886, in discussion of Mr. J. M. Wilson's specifications. The opposite views then expressed had able supporters, and it seemed impossible to reconcile them; nor since that time have there been, to my knowledge, any further experimental data to throw light on the question.

I have made extended use of both the forms:

$$f = \frac{w}{n}(1 + \phi)$$

$$f = \frac{w}{n}(1 + \tfrac{1}{2}\phi)$$

the former in the case of railway bridges, since it, to at least some extent, makes allowance for impact; the latter for roadway bridges, wherein, no matter what view is taken, there is a difference, both in kind and degree, in the manner of application of live load from that occurring in railway bridges. As the foregoing formulas are essentially those based on ultimate strength, it seems consistent that a specification employing them should likewise use post formulas based on ultimate resistance. If one regards the matter from the point of view of primitive elastic capacity, this view should be carried out to embrace compression members as well.

In Mr. Cooper's specification, by using one-half the working stress for live load that is allowed for dead load, inferentially he adopts the view that a live load is twice as destructive as a dead load, a view, in my judgment, well to take, especially considering the dynamic action of live load coupled with shock. Mr. Cooper assesses the necessary section in a member as depending on the absolute amounts of dead and live stress acting thereon, the ratio of minimum to the maximum stress not being involved. As I understand the Wöhler experiments, the range of stress variation was what was primarily considered, the ratio of minimum to maximum stress not necessarily entering into the expressions covering the results. However this may be, and however admirably the Launhardt formula fits the case for railroad bridges, in roadway bridges the manner of application of the live load does not in any way conform to the way in which the experiments which gave rise to the formula were conducted.

Referring again to the form

$$f = \frac{w}{n}(1 + \phi),$$

which includes an allowance for impact, the broad assumption was made that the effect of impact diminishes with the increased weight of the member, and as the weight of the web members increases with tolerable uniformity from the center to the ends of the span, equally so the ratio ϕ. On this assumption the formula, $a = \frac{2}{3}t\,(1 + \frac{1}{2}\,.\,\phi)$ was changed to read, $a = \frac{t}{2}(1 + \phi)$.

There was then a reduction in the value of w of 25 per cent., which vanishes when $\phi = 1$, since then the load being all dead, $a = w = t$. This formula if applied to web members and floor systems works well, but it is not clear why it should apply to chords with the same value of $\frac{w}{n}$; for though in chords and end panel diagonals the values of ϕ are about alike, the manner of application of the stresses is by no means similar. The live load acts directly on the stringers, less directly on the cross-girders, is thence conveyed to the web members, and so to the chords, and the values of ϕ through this series do not, I think, cover the history of impact effect; for in any diagonal bar, for example, part of the live load stress gets there by direct load, and part by the cumulative effect from the other web members nearer the loaded abutment—with relatively little impact from cumulative stress, and considerable from direct load applied at the foot of the bar. It would seem more in accordance with the actual state of affairs to deduce the working stress in a member by the formula $f = \frac{w}{n} (1 + \frac{1}{3} \phi)$ where $w = \frac{2}{3} t$, and then reduce f by an amount dependent alone upon the amount of direct live stress, the manner of application and liability to shock, etc.

The only recognition I have seen of something like this point of view appears in the specification for the Pennsylvania lines west of Pittsburgh, wherein the impact is covered as follows: "Twenty-five per cent. shall be added to the above load (the engine loading) in calculating the floor system. Twenty-five per cent. of the *maximum panel load* from the above engine shall be added to the stress on all vertical members of the web system, and its oblique equivalent to all diagonals, including end braces." (The italics are mine.) And for riveted bridges on same line, "twenty-five per cent. shall be added to the above loads in calculating the floor system. The girders shall be calculated for an addition of 25 per cent. for spans of 20 feet or less, and diminish uniformly to 10 per cent. for spans of 100 feet."

In applying the method of calculation of $p + Q$, 25 per cent. would be added to the stress in web members due to one panel load, $\frac{pl}{n} + Q$, $\frac{l}{n}$ being the panel length; and 25 per cent. to the stresses due to $p + Q$ for floor systems and short spans, diminishing to 10 per cent. for 100-foot spans.

Calculating by engine concentrations, the panel load spoken of might be considered the maximum cross-girder load, since in any absolutely correct method of calculating stresses from engine loading panel loads are not involved. The idea advanced on page 52 could be stated thus: That part of the live stress which gets to a member by cumulative effect to be allowed for, in connection with the dead stress, by $f = \frac{w}{n} (1 + \frac{1}{3} . \phi)$, repetition of loading being the governing principle; the remaining live stress—the amount which acts on the member directly—that is, its static amount—to be allowed for at no greater unit than 6,000 pounds per square inch; then each member will, in my judgment, be proportioned closely to accord with the real action of the loading. It will be noticed that this will give a varying percentage of total live load stress for impact, to each member.

The specifications just referred to—those of the Pennsylvania lines west of Pittsburgh—are, in my opinion, among the best in existence, certainly the best emanating from a railway company. And they contain in germ, at least, what would be my reply to many points raised by Mr. Waddell in his paper, notably in regard to the following: Spacing of stringers and deck plate girders; use of end floor beams; stiffening the two end panels of the lower chord; "squaring" the ends of stringers on skew bridges; camber in pin connected and riveted bridges; minima sections and thicknesses; and generally the requirements regarding plate girder bridges.

By Ward Baldwin, M. Am. Soc. C. E.

In the consideration of the question as to whether a concentrated or uniform loading should be used, there is one class of problems that seems to be often overlooked; but the frequency with which they occur warrants a careful consideration of them in devising a scheme of loading for general use. The railroad engineer is not only concerned with the loading for his bridge specifications, but he is frequently called upon to determine whether some special engine or other concentrated load can go over his road without damage to the existing bridges; and it is not unusual for him to decide whether a certain class of engines may or may not be used on the road.

To solve problems of this kind readily it is necessary to deal with the actual concentrations, or to have some general method of arriving at close approximations. The method proposed by the author requires the determination of the empirical co-efficients in the formula $W = A + LB$ for each loading, and so would be of no assistance in the solution of such problems as noted above, unless the tables covered a very wide range. The method of using an equivalent uniform loading, determined from the maximum shear in the end panel, first proposed by Mr. C. L. Strobel, M. Am. Soc. C. E., has proved the most generally useful approximation yet published. The author has used "Class A" in finding percentages of error involved in the approximations he uses. It is to be noticed that in the case of this loading, the weight of the engines per linear foot exceeds the uniform load per foot by only 10 per cent. It is not surprising that the approximate solution proposed does not in this case give a large percentage of error; but the limit of error may not be so small for a loading like Class U, where the engine load per lineal foot is 23 per cent. heavier than the uniform load per linear foot.

The author quotes the usually allowed unit stress for shear on the webs of girders, viz., 4,000 pounds for iron, and 5,000 pounds for steel. There seems to be no good reason why, at least in the case of steel, the working stress for shear should be less than 80 per cent. of the working tensile stress.

By A. C. Stites, Assoc. M. Am. Soc. C. E., and Lee Treadwell, Jun. Am. Soc. C. E.

Having been associated with Mr. Waddell in the production of his paper, there is little in the way of original discussion for us to prepare, but we would like to submit some of the valuable results acquired during the various investigations incident to work upon the paper, as an additional contribution to the general good. While the results were arrived at by precise mathematical methods, they were given expression, in the curves (Plates XXIV-XXV) appended to this discussion and the formula herewith submitted, more with a view to practical utility than to scientific refinement. In no case, however, will results obtained from the curves or formula depart from actual conditions enough to warrant their use in any connection being questioned. The formula gives its most exact results for spans from 20 to 35 feet (and was constructed with this end in view, as between these limits lie the panel lengths most largely used), and is as follows:

Maximum end shear = w + ½ (panel length × equivalent uniformly distributed load), where w = A + BL, in which L is the span length and A and B constants to be found in the table given below.

CLASS

	Z	*Y*	*X*	*W*	*V*	*U*
A..................	8 500	9 500	10 500	12 000	13 000	14 000
B..................	100	105	110	115	120	125

By G. H. Blakeley, Jun. Am. Soc. C. E.

The correct proportioning of railway bridges, in all their parts, to properly resist the varying stresses produced by service, began with the introduction of the specification of concentrated live loads. How often is the engineer reluctantly compelled to condemn bridges built under the old requirements for a uniform load, the same for all spans; which, though highly strained in general, are dangerously so in some members only, such as counters and floor system, due to the inadequate provision for the proportionally higher stresses on these members resulting from actual loads. If the method of engine concentrations has entailed somewhat laborious calculations, the labor has not been expended wholly in vain, for it has been the investigation of the static stresses imposed by actual conditions, which makes the substitution of a sliding scale of equivalent uniform loads possible.

It cannot be successfully contended that the process of calculation for concentrations of loads is as easy or as rapid as for uniform loads, though the labor required in the former is overstated by Mr. Waddell. Those who are almost daily obliged to make such calculations for the design of railway bridges in competition, have found some "short cut" by means of which the labor is greatly abridged, and results obtained, if not of precision, yet of sufficient accuracy for constructive purposes. The graphical method by moment polygons furnishes an easy and rapid mode of deriving results, and by following the method outlined in Sections 72 and 74 of DuBois' "Graphical Statics" the stresses in an ordinary truss, when once the polygons are made, are obtained with less labor and in but little more time than would be required to calculate them for a uniform load.

While no one contends that the actual loads on bridges are identical with the assumed typical concentrations, or that the actual stresses are the same as those calculated therefrom; yet the growth of the increasing weights of motive power on railways has been and continues to be in the direction of the well designed typical loads, and the actual static stresses are proportional to the quantities on our strain sheets. The typical concentrated loads, approaching actual loads as they nearly do, furnish a standard of the capacity of a bridge which can be comprehended by the ordinary railway manager, more readily than any combination or schedule of uniform loads. That this is appreciated by many railway superintendents, who are not engineers, is evident from the fact that they act upon it by ordering their bridges to be built to carry a definite type of locomotive, most frequently the heaviest then in use on their line.

The greatest burden connected with the system of concentrations is not so much its use, as is the unnecessary diversity in the amount and arrangement of the loads made by the specifications of the different railways. The practice among the smaller railways is to specify an actual existing train load, and too frequently before the new bridge is upon its pedestals, new and heavier motive power is ordered or in use. Nearly all the railways have their own standards of loading, differing but slightly from one another in their final effect. It is due to this almost endless variety of loads, that the computer of the bridge company is forced to adhere to the method of calculation by concentrations.

When a certain railroad intends to build a bridge and invites a dozen bridge companies to tender proposals, instead of making the labor of designing as easy as possible by adopting a live load the same as the well considered types of any of its near neighbors, it specifies a concentrated loading of unique arrangement. The computer intrusted with the preparation of the design has not seen such an arrangement of loads before, and for anght he knows will not have to deal with it again, hence instead of endeavoring to discover a uniform load producing the same strains, and the conditions and limitation under which it would have to be applied, he finds it easier, quicker, and more satisfactory to proceed at once and determine the actual strains from the concentrations themselves. It would seem to be the wiser plan not to abolish the typical standards of loads; but to have fewer standards, arranged in gradation similar to those proposed by Mr. Waddell, to suit the requirements of the service on different railways. Tables of equivalent uniform loads being prepared for these types, it would be left to the preference of the computer what method of calculation he would use.

The adoption of Mr. Theodore Cooper's specifications has done much in this direction, and it is to be hoped that Mr. Waddell will receive sufficient encouragement to prepare tables of uniform loads, representative of the several types of loads accompanying his paper, as an inducement to railway engineers toward the adoption by them of the particular type best suited to their requirements. If this paper shall result in calling attention to the needless diversity in load specifications and lead to a general adoption of standard types, it will have served a most admirable purpose, and lifted from the shoulders of the engineers of the bridge companies "a burden grievous to be borne."

The employment of an integral number of feet for wheel spacings is an undoubted convenience. The weights of the tenders are, however, too light. If the weights on each axle were increased 2,000 pounds, the resulting weights would not be in excess of the actual weights of the tenders used on the leading railways in the vicinity of New York. The neglect to specify the loading produced by the heavier eight-wheel passenger engines is an indefensible omission. It is not always possible to have long panels. Ten and 12-foot panels are unavoidable sometimes, and, upon stringers of this length, the maximum strains are produced by the drivers of the passenger locomotive. To cover this effect it is not necessary to provide two distinct sets of typical loads, but only to specify as an additional loading, "80,000 or 100,000 pounds on two axles, 8 feet apart," and it will not be necessary to make two calculations of strains, as the effect of the alternative loading is felt only on short spans, say under 12 feet.

The adoption of the proper live load is a question worthy of considera-

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TRANS. AM. SOC. CIV. ENG'RS
VOL. XXVI. No. 522.
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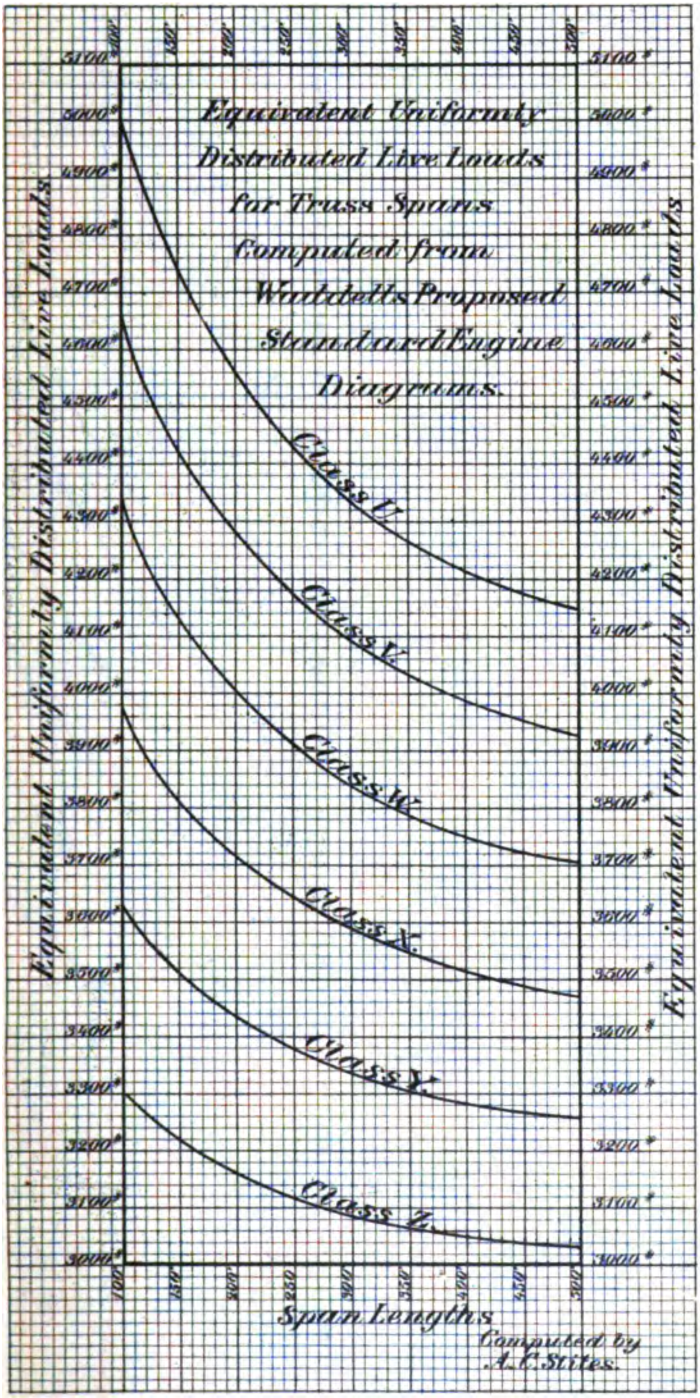

PLATE XXV.
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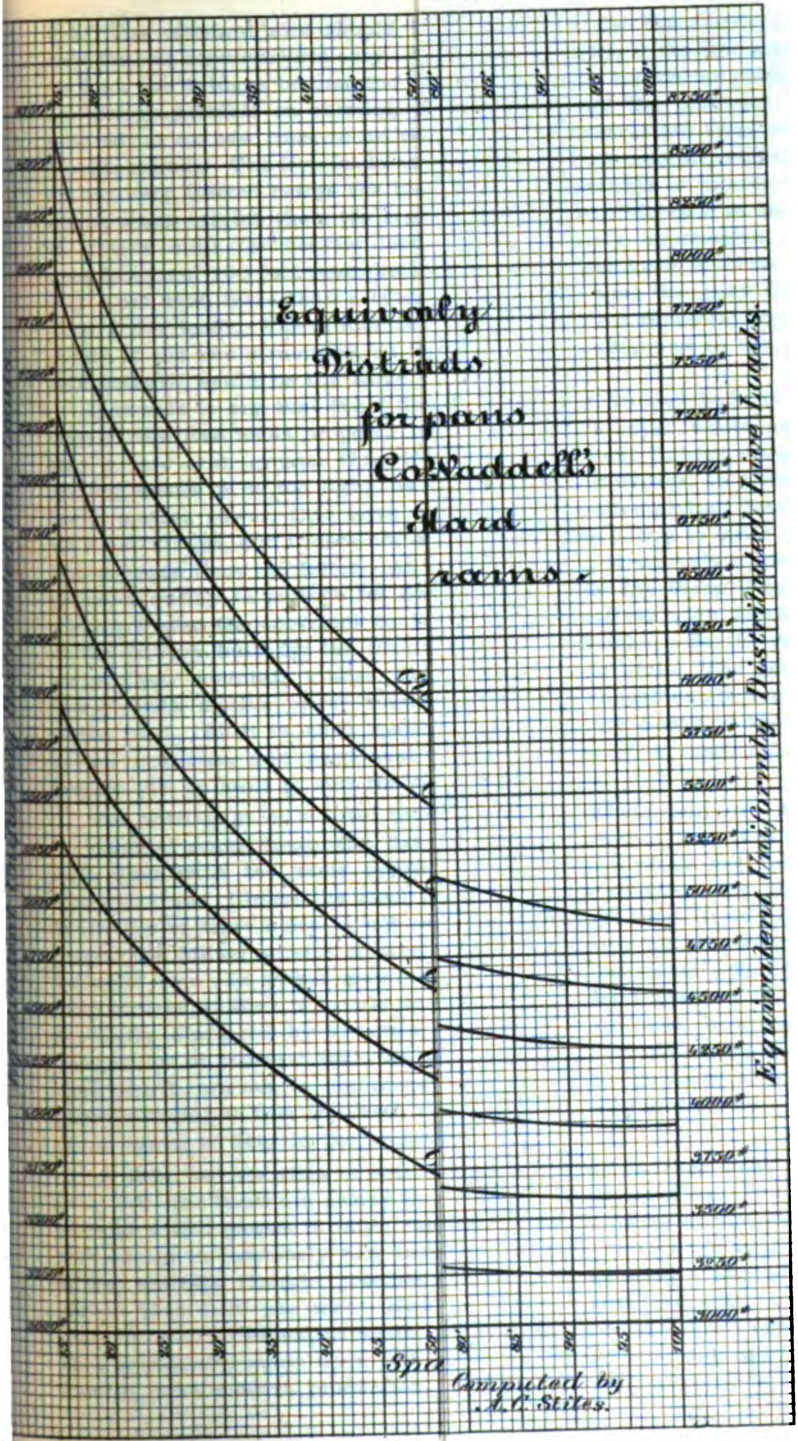

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tion. The constant aim should be to construct for the future and not to meet present requirements only. On the other hand, if the live load is taken too high the bridges become too costly, and, with limited expenditure, it is not always possible on existing lines to make all the renewals as fast as required, or on new lines to make the cost of construction come within reasonable bounds. The live loads are taken as low as possible, and the bridges are not long erected before the increase in the weights of motive power and rolling stock strains them too highly. The slight difference in the first cost of bridges built for heavier loads is not properly appreciated. A single track bridge of 150 feet span, built to carry the live loads of Class X, weighs only 4 per cent. more than a bridge of the same span designed for carrying Class Y live loads. The difference in weight does not represent the difference of cost of the two structures, as the labor in the shop and in the erection of both bridges would be the same.

It is safe to say that the difference in cost of bridges built to carry any class of the live loads proposed in Mr. Waddell's paper would not be more than 3 per cent. greater than if built for the next lighter class. Class Z loading seems to be too light, as there are few railroads, in these times of heavy motive power, that have not in use or contemplation locomotives of the Class Y type, and it does not seem to be a wise policy to build bridges for lighter loads than the latter. At the other limit, it scarcely appears to be a judicious outlay to provide for heavier loads than the Class V type. Those who have seen the enormous consolidation locomotives with 140,000 pounds on the drivers, built for the Union Pacific and Northern Pacific railways for use on their mountain grades, can appreciate this limit. The general adoption of such motive power would require the almost entire reconstruction of the road. As it is, such special locomotives are now and then built for special purposes, and used over small portions of a road, on which the bridges can be built to suit the conditions.

The testing of mild steel under many conditions, and its subjection to all kinds of rough treatment, has convinced the writer that it is safe to use such steel with the same processes of manufacture as are in vogue for wrought iron. Unless the steel is of very high tenacity, the precaution of reaming the rivet holes is not needed much more than it is for iron, and indeed the milder grades of steel show less injury by punching than does wrought iron. In either metal the reaming is beneficial. The notion that mild structural steel is brittle and like the material used for tools, is being gradually displaced by a better knowledge; and there is a more general recognition of the fact that the structural steel of to-day, produced by the open hearth process, is not properly steel at all, but more or less a homogeneous wrought iron in which the absence of slag and cinder prevents the development of fiber in the processes of rolling.

A thin, narrow strip of soft steel with a hole punched in it can be bent over until the faces are nearly in contact, without cracking through the line of bend which passes through the punched hole. This cannot be done with iron except in extremely rare instances. The time was not long since when it was scarcely thought possible to produce steel with a less percentage of carbon than 0.30 per cent. Now it is easily produced with only 0.12 per cent. or less. The experiments on the injurious effects of punching have been principally made upon this higher steel and very few upon the milder steel of more modern production. More extended acquaintance has brought increased confidence in the capacity of mild steel for structural purposes, and there is now as much steel used in construction with the same process of manipulation as wrought iron, as there is reamed and planed.

It is, however, not advisable to use steel of high ultimate strength without reaming the punched holes. The limit above which reaming should be required should be placed at about 70,000 pounds. Steel of this quality will stand the drifting test of an enlargement of 50 per cent. at least, and the writer knows of steel of 80,000 pounds ultimate strength which has withstood an enlargement of 100 per cent. The drifting test is a valuable adjunct in the way of testing, but it should not be made the final test.

The formulas suggested by Mr. Waddell permit too high an intensity of working stresses in short spans. There seems to be a general agreement in the results obtained from the best specifications to allow about 10,000 pounds per square inch on the lower chord iron eye-bars of spans of from 125 to 150 feet. Tests of full size steel eye-bars do not warrant the assumption of more than 25 per cent. excess of strength over iron eye-bars. This would make the permissible stress in the bottom chord bars of a 150-foot span, if of steel, 12,500 pounds per square inch. Mr. Waddell's formula would permit 14,000 pounds per square inch. Mr. Cooper's specification would permit but 11,500 pounds per square inch on the same bars, and this latter figure is certainly not too low for such short spans, where rigidity is an important consideration, and impact an important factor.

By Henry W. Hodge, Jun. Am. Soc. C. E.

Mr. Waddell's paper will doubtless help to advance the science of bridge designing to a nearer approach to that uniformity which all engineers look forward to, and the suggestions he makes will be most eagerly welcomed by all those unfortunates whose duties compel them to make the computations necessary for bridge designs under modern specifications. That wheel concentrations are an unnecessary refinement and a source of much needless labor, all engineers are agreed, but the question is where to draw the line between figuring with wheel concentrations and with uniform load.

In the writer's opinion it is undoubtedly best to use wheel concentrations for stringers, floor beams, long verticals and such secondary members, also for plate girder spans; as any one can readily make a table of exact maximum bending moments for all spans, for any particular engine, in two or three hours, which is good for all time, and consequently requires no labor in practical use. Furthermore, such a table is as easily prepared and more quickly used than Mr. Waddell's table of equivalent uniform loads. Such plate girder spans might be used up to 75 feet, as Mr. Waddell's limit of 90 to 100 feet seems rather long for practice. Such girders become too deep and heavy to transport, besides requiring several covers, and this latter feature is objectionable, as Mr. Waddell points out. Wheel concentrations might also be used for lattice girder spans up to the same or a greater length, say to 90 feet, but for all spans over this length a heavy uniform load with one concentration would seem to answer every purpose.

It seems to be going from one refinement to another to change from wheel concentrations to a uniform load varying not only for every length of span,

but also for the chords and webs; and as one of the main objects of any change is to simplify the routine work of bridge computers, let it be simplified, and do not drop one burden to assume another, as Mr. Waddell's scheme of loading would do.

Take a large enough load, say 5,000 pounds per linear foot, with an additional 30,000 pounds concentrated at any point for spans up to 125 feet, and 4,000 pounds per linear foot, and an additional 30,000 pounds concentrated at any point for spans over this length. These loads are now in use by the Southern Pacific Railway, and they seem to be heavy enough to cover any further increase in live load that may arise in the near future. Doubtless this simple loading will be objected to on the ground that it is not exact and scientific; but those wishing scientific loading had by all means better use wheel concentrations, as nothing as scientific can be found, and the only object of the change is simplicity, which this loading gives most completely.

Mr. Waddell calls attention to the indirect effect of wind loads, and while such effects would seem to be a very unnecessary refinement, yet if they are to be considered at all, one of the most important ones would doubtless be the increased load on the leeward stringers due to the overturning effect on the train, amounting to about 300 pounds per linear foot in ordinary cases; yet Mr. Waddell does not include this in his list of such indirect effects.

It certainly seems unnecessary to increase the general allowance for wind pressure of 150 pounds per linear foot of upper chords and 450 pounds per linear foot of lower chords, for ordinary spans, or to add one more burden to the computer by making him figure the area of his truss to get some equally arbitrary amount derived from such area. That the present pressures are fully sufficient seems to be well proven by the fact that there are many old railroad bridges standing to-day, having weathered hundreds of storms, with laterals of one-quarter the strength required by modern practice. While such bridges are not cited as examples of good engineering, they do seem to prove that four times their lateral stability should certainly be safe.

Mr. Waddell's floor system is certainly a good one, but if willing to incur such expense, it would seem better to use a buckle plate or trough section floor, with ties in ballast, which would be very little more expensive if maintenance is considered. As to unit stresses, there certainly seems room for a large amount of simplification in modern specifications, as most of them attempt to split hairs under this head, whereas, the true strength of the material is, to a large extent, uncertain. While it would seem that our English fellow-engineers have possibly reached an extreme position in their ordinary specifications of "compression tons per square inch: tension m tons per square inch," yet a nearer approach to such delightful simplicity would certainly be a boon to bridge designers.

By J. A. L. Waddell, M. Am. Soc. C. E.

In beginning this *résumé* of the preceding discussions, I desire to express to the gentlemen who have contributed my hearty thanks for the time and attention they have given to the paper and for their valuable additions to the literature of bridge engineering.

Without their contributions my paper would have had but little effect; but with them it bids fair to accomplish a number of much needed reforms, and to effect a simplification of bridge engineering practice, all of which will be clearly set forth at the end of this *résumé.* Although some forty members of the Society have taken part in the discussion, making it probably the most thorough and exhaustive that has ever been given to any of the Society's papers, nevertheless it is to be regretted that the names of half a dozen prominent American bridge engineers are conspicuous by their absence.

In preparing this *résumé,* I shall take up the various subjects treated in the paper one at a time, in the order in which they there appear.

Uniform vs. *Concentrated Loads.*—It is a matter of regret to me that several of the gentlemen discussing have failed to appreciate the true intent of my proposition to substitute equivalent uniformly distributed loads for engine concentrations followed by uniform car loads. If they had not misunderstood, they would surely never have stated that there is less labor involved in either the concentrated wheel load method, or the locomotive excess method, than there is in the method of equivalent uniform loads.

If it be remembered that it is my desire to have in every railway bridge specification a diagram or diagrams of equivalent uniformly distributed loads, similar to those contributed by Messrs A. C. Stites and Lee Treadwell in their discussion, together with a table of constants for the end shear formula, or perhaps, preferably, another diagram giving end shears for all plate girder spans, and to have it stated distinctly in the specifications that these equivalent loads are to be used exclusively instead of engine diagrams for all plate girders and trusses of single intersection; I think it will be evident that what I propose will be a great labor-saving scheme. Perhaps the misunderstanding is partially my fault, for I may not have made my statements as clear as is desirable.

Let us follow rapidly the steps that it will be necessary for a computer to take in finding the stresses in a single-track, long-span bridge with broken top chords, when using diagrams of equivalent uniform loads similar to those of Messrs. Stites and Treadwell.

First.—In proportioning stringers, find from the diagram the equivalent live load for the panel length adopted, add thereto the weight per foot of two stringers and the track, and divide the sum by two, calling the quotient w; then the moment will be $\frac{1}{8} w L^2$, where L is the panel length.

Second.—To obtain the concentrated load on a floor beam at the point of attachment of stringers, find the equivalent load for a span of $2 L$, to it add as before the weight per foot of two stringers and the track, and divide the sum by two, calling the quotient w'; then the concentrated load sought will be $w' L$.

Third.—To find the dead load stresses in trusses, assume the dead load per lineal foot per truss (w''), and compute the panel dead load and the dead load reaction at each pedestal, then by a single graphical manipulation find the chord and web stresses on one-half of the truss, checking all the work by computing analytically the top chord stress at mid-span.

Fourth.—To find the live load stresses on chords and inclined end posts, take from the diagram the equivalent load for the entire span length and divide it by two, calling the quotient w''', then set a slide rule to the ratio $\frac{w'''}{w''}$ and read off from it continuously (by using the dead load stresses previously found), all the live load stresses in chords and inclined end posts.

Fifth.—To find the live load stresses in web members, assume a reaction of 10,000 pounds at one pedestal caused by a load (its amount need not be calculated) at the first panel point from the other pedestal, then by a single graphical manipulation ascertain and write down all the web stresses produced thereby from end to end of span. Next calculate the shears R_1, R_2, R_3, at the head of the train for all positions of the same, using the slide rule. Tables of such shears given in most textbooks on bridges will shorten these calculations. Then, with the slide rule again, find the correct web stresses by the following proportion: as 10,000 pounds is to any one of these shears, so is the corresponding web stress just found to the correct stress.

Now can any imaginable method be simpler, easier, or prettier than this? I doubt it. Contrast it with the long and wearisome method by engine diagram, involving as it does for stringers and floor beams, the shifting of wheels, calculation of reactions for each wheel load in order to obtain total reactions, and the computing of moments from these reactions and loads; also very often a repetition of the calculations for a different position of wheels. Then when it comes to the trusses, what interminable labor is involved! I have seen a good computer of one of our largest bridge companies calculate the shear on the lower half of a main diagonal, for five different positions of the moving load, in order to obtain the absolutely greatest value. This was before Professor DuBois published his method of ascertaining the position of wheels for maximum shear with inclined top chords, to which reference is made in my paper, and which Professor DuBois himself is only too glad to acknowledge to be extremely laborious in its application.

For such a bridge as the one assumed, the time required for computing exact maximum stresses is, as stated by Mr. Thacher, fully ten times as great as that required by the equivalent uniform load method; and for the most simple case of a short span with equal panels and parallel chords, I am convinced that I am understating the case in my paper by admitting the ratio of time required for the two methods to be as two is to one.

Now comparing the method of using a uniform car load, constant for all span lengths, headed by a concentrated load, or the more accurate one of using the same car load and two concentrated loads separated by about fifty feet or two ordinary panel lengths, advocated by Messrs. Burr, Swain, Ricketts, and others, with that of the equivalent uniform load, we will find that as far as the floor system is concerned there is but little difference in the time and labor for the three methods; but that in respect to the trusses, both of these items are more than twice as great for the concentration methods as for the equivalent uniform load method. This is evident for the reason that, in addition to making all the calculations indicated in items Nos. 4 and 5 in the previous comparison, it is necessary to find the stress in every chord and web member for either one or two panel excess loads, which in itself involves more labor than does the finding of the stresses by equivalent uniform loads. Moreover, I doubt that the method of constant car load, combined with one or two concentrated loads, can be made to give for all cases as correct results compared with the theoretically perfect method, as will that of the equivalent uniform loads.

A proof of this is given by the results of some calculations made by Messrs. Stites and Treadwell, at the time their tables were computed. I had anticipated using for web members a uniform car load with two engine excesses until I saw the results of the calculations just mentioned. The following table gives the shears in web members by the engine excess method, and a comparison of them with those computed by the theoretically perfect method, also a comparison of the percentages of error for this case and that of the equivalent uniform load method, omitting from consideration the four-panel 100-foot span, which really should never have been incorporated therein because of several objectionable features, more especially its unsightly appearance. The only reason for incorporating it was to fill out the table; for every 100-foot span should have at least five panels.

By comparing the last two columns it will be seen that the locomotive excess method for web members always gives an error on the side of safety, and that these errors are much larger than those given by the equivalent uniform loads. Taking the average of said errors we find that for the locomotive excess method to be 7.34 per cent. on the side of safety, while that for the equivalent uniform load method is a trifle less than 1 per cent., also on the side of safety.

Time will not permit me to compute the errors in chord stresses by the

SPAN.	MEMBER.	SHEAR IN POUNDS.			PERCENTAGE OF ERROR.	
		By Diagram.	By Uniform Load.	By Uniform Car Load with two engine excesses.	By Uniform Load.	By Uniform Car Load with two engine excesses.
150-foot	End Post......	205 285	200 745	208 833	2.21 Danger	1.73 Safety
	1st M. Diagonal	134 585	133 830	141 000	0.56 Danger	4.76 Safety
	2d M. Diagonal	78 142	80 298	85 667	2.76 Safety	9.63 Safety
	1st Counter....	36 576	40 149	42 833	9.77 Safety	17.11 Safety
200-foot	End Post......	281 874	275 716	286 500	2.18 Danger	1.64 Safety
	1st M. Diagonal	209 902	206 787	216 875	1.53 Danger	3.28 Safety
	2d M. Diagonal	148 784	147 705	156 625	0.72 Danger	5.27 Safety
	3d M. Diagonal	97 484	98 470	105 750	1.01 Safety	7.45 Safety
	1st Counter....	55 768	59 082	64 250	5.94 Safety	15.21 Safety
	2d Counter....	26 220	29 541	32 125	12.66 Safety	22.52 Safety
250-foot	End Post......	357 668	349 875	363 100	2.18 Danger	1.52 Safety
	1st M. Diagonal	285 278	279 900	292 400	1.88 Danger	2.50 Safety
	2d M. Diagonal	220 844	217 700	229 200	1.42 Danger	3.78 Safety
	3d M. Diagonal	164 804	163 275	173 500	0.93 Danger	5.27 Safety
	4th M. Diagonal	116 264	116 625	125 300	0.31 Safety	7.73 Safety
	1st Counter....	75 887	77 750	84 600	2.45 Safety	11.48 Safety
	2d Counter....	43 645	46 650	51 400	6.85 Safety	17.80 Safety
300-foot	End Post......	433 260	424 182	439 167	2.10 Danger	1.36 Safety
	1st M. Diagonal	360 438	353 485	367 750	1.93 Danger	2.03 Safety
	2d M. Diagonal	293 893	289 215	302 583	1.59 Danger	2.96 Safety
	3d M. Diagonal	234 684	231 372	243 667	1.41 Danger	3.82 Safety
	4th M. Diagonal	181 734	179 956	191 000	0.97 Danger	5.02 Safety
	5th M. Diagonal	135 034	134 967	144 583	0.05 Danger	7.08 Safety
	1st Counter....	95 206	96 405	104 417	1.26 Safety	9.68 Safety
	2d Counter....	62 431	64 270	70 500	2.95 Safety	12.95 Safety

use of the locomotive excess method; but I feel quite certain that the results would show, as in the case of the diagonals, the errors all to be upon the side of safety, but by no means as great as those for the diagonals. Mr. Treadwell has figured by the locomotive excess method the moments for the 200-foot span, which can be taken as an average case, and finds that the greatest error is 4.64 per cent. and the least 1.68 per cent., all errors being on the side of safety, and the average error being 3.53 per cent. For the equivalent uniform load the greatest errors are 1.45 per cent. on the side of safety and 2.14 per cent. on the side of danger, the average being 0.16 per cent. on the side of danger.

The large errors in chord stresses by the locomotive excess method are due partially to the fact that in this method cars precede as well as follow the locomotives, while in the engine diagram method there are no cars ahead of the engines. In my opinion, as cars ahead of engines are an unusual load, and as, when they are found there the chances are that some of the cars are not loaded up to the limit of the specifications, it is well to ignore such unusual loading.

Mr. Treadwell finds that with Cooper's Class A as a standard, the engine excess in order to give exact agreement for plate girder spans, should vary from 11,300 pounds to 23,600 pounds, the average being 20,000 pounds. Adopting the latter, the greatest percentages of error would be 5.24 danger and 5.39 safety. For floor beams he finds the average concentration to be 20,700 pounds, with extreme errors of 4.12 per cent. danger and 4.11 per cent. safety. But if 20,000 pounds be adopted as the proper concentration, the last-mentioned errors would be 5.16 per cent. and 3.58 per cent., respectively. These figures show very plainly that the method of using a constant uniform car load with two engine excesses, as far as the trusses are concerned, cannot be made to give stresses approximating to the theoretically exact stresses as closely as can the method of equivalent uniform loads.

Again it is evident that a single concentration at the head of a train will not give as close an agreement as will two concentrations separated by two ordinary average panel lengths, for the latter method distributes the load more nearly in accordance with the actual distribution. It is true that the concentration at the head of the train need not equal the difference between the total weight of two locomotives with their tenders and the weight found by multiplying the extreme length of the two locomotives and tenders, coupled, by the car load per linear foot, although such a method would be considered by most engineers to be the proper one; but it is more than likely that, if the single concentration were adjusted so as to give for all truss members the best average in respect to theoretical correctness, the errors would be greater than those found by using equivalent uniform loads, and that the errors for the floor system would be still greater.

My opinion of the single-concentration-with-constant-car-load system is, that it could be used advantageously as a standard, if deviations on the side of safety of considerable amount be not deemed objectionable; but that, to replace any particular standard load of two engines followed by a constant car load, it is inapplicable. Certainly, as far as simplicity and saving of labor are concerned, it is much preferable to the engine diagram system. But why adopt it when there is another method that is about twice as simple of application and gives results agreeing much more closely with the theoretically correct ones?

An objection that may be raised to my proposed equivalent uniform loads is, that chief engineers and bridge engineers of railroads will not adopt them; but it is hardly fair to assume that these gentlemen are unreasonable and unwilling because of a little extra trouble, to concede a point that is evidently for the general good. I purpose making it my business to communicate in the near future with all of these gentlemen whose names are given in Poor's Manual, so as to obtain their views on this and one or two other points.

I would say here that the preparation of diagrams giving equivalent uniformly distributed loads for all spans—and end shears on plate girders, to correspond to any proposed standard train load—involves by no means a great amount of labor, and that they can be furnished by any expert bridge engineer for a small fee. One who has made a number of such diagrams can easily make others by finding a few points on the new curve and using a previously found curve for a similar load as a guide. Where the plotted points show slight irregularities, it is much more scientific to draw a curve of some regularity without deviating from them essentially than it would be to follow the variations; for the latter are due to peculiar relations between the span lengths and the wheel spacings, which would not exist for slightly different engines. I have called attention to this in the paper, but do so again here on account of its importance.

Answering Mr. Thomas H. Johnson, I would suggest that it is not quite fair to condemn the equivalent load method because the shear on a counter for a 100-foot span through bridge having only four panels (a structure which, as before stated, should never be built, and which was employed in the table merely for the sake of continuity) involves an error of 20 per cent. If we discard the 100-foot span from the tables, we find that the errors for counter stresses vary from 1.26 per cent. safety to 12.66 per cent. safety, the greater errors being always in the smaller counters. Are not such errors in the method an excellent fault? What practical engineer is there who proportions light counters for the stresses shown on the strain sheet, even in competition?

If we leave out of consideration the counters as well as the entire 100-foot span, we find that the greatest errors in chords and diagonals are 2.21 per cent. danger and 2.76 per cent. safety, the averages being approximately 1.8 per cent. danger and 1.2 per cent. safety, and the average for all members of all structures only 0.3 per cent. danger. Surely these errors are small enough in all conscience, and be it remembered that they cover all stresses in main members (counters excepted) for all spans from 150 to 300 feet.

Still replying to the same gentleman, I would state that the shear formula or diagram for plate girder spans will rarely be used by computers, who always endeavor to have an excess of section in web plates. It is only in the case of shallow girders, or middle girders for double track structures, that the webs need to be tested for shear.

Professor Eddy writes as follows: "But in short spans, and in stringers and other details of long spans, where the wheel concentrations exert a more preponderating influence, I am led to believe that it will still continue to be required that the designer and computer shall take account of the wheel concentrations, however much he may dislike the work, or however certain he may be in his own mind that it involves unnecessary labor." If Professor Eddy will study the equivalent load system, he will find that for stringers, floor beams, etc., it gives results which are practically exact (excepting the shear formulas or diagrams that, as before stated, need hardly ever be used), and that the errors involved occur in the trusses.

Mr. Fulton's method of plotting the loads and spans in order to find actual concentrations at panel points is antiquated and extremely laborious, and is justifiable only in case of a double system of cancellation.

Mr. Douglas' calculations do not militate at all against the equivalent uniform load method, as that method is not applicable to trusses having multiple systems of cancellation. It merely affords another corroboration of my objection to the Whipple truss as being uneconomical as well as unscientific. Where two heavy concentrations are thrown upon one system, as in this case, there is evidently a want of economy in the design.

Mr. Hodge does not understand the proposed equivalent uniform load method, for it is really correct for "stringers, floor beams, long verticals, and such secondary members; also for plate girder spans." By adopting it the engineer, who prepares the specifications, in furnishing equivalent uniform load diagrams saves for bridge computers for all time to come the useless labor involved in dealing with wheel loads.

Mr. Hodge's proposed moment table is no more easily used than my diagram; for he has to compute the dead load moment by the formula $M = \frac{1}{8} w' L^2$, and add it to the moment given by his diagram; while I add the equivalent load w given by my diagram to the dead load w' making the sum $= w''$, and obtain the moment by the equation $M = \frac{1}{8} w'' L^2$. Mr. Hodge is mistaken in stating that the equivalent uniform load must vary for chords and webs; for I give but one equivalent load for each span length.

I would like to call the reader's attention to Prof. Du Bois' pointed and forcible remarks upon the subject of uniform vs. concentrated loads.

Of the forty-two gentlemen who have contributed to the discussion of this paper, four have not touched at all upon the subject of live loads, and seven more have expressed no decided preference for any of the three systems. Of the remaining thirty-one, sixteen are in favor of the equivalent uniform load system, eight are in favor of the locomotive excess system, and seven are in favor of the engine diagram system. It is fair to assume, therefore, that the engineering profession is tired of the engine diagram system, and is prepared to adopt either the equivalent uniform load system, or the locomotive excess system, the preference being decidedly in favor of the former.

Now, I am going to ask all of the forty-two contributors to the discussion, to be so kind as, after reading carefully all that has been said upon the subject, to vote upon the question as to which of the three methods they finally favor, and to this end I shall ere long communicate with each of them.

To the gentlemen who have advocated the locomotive excess method I would say that all of the rather limited calculations which I have been able to make, induce me to conclude that it is impracticable to find such a leading concentrated load as will give results for both floor system and trusses, which will agree at all closely with the theoretically correct results obtained by the engine diagram method; and that the equivalent uniform load method does give such an agreement close enough for all practical purposes, provided that multiple systems of cancellation be not used. The *onus* is now on them to show that I am mistaken, and that the locomotive excess method does give an agreement with theory that is close enough for all practical purposes.

Be it remembered, though, that I do not claim such agreement to be essential, for a uniform car load preceded by a single concentrated load can be used as a standard instead of a uniform car load preceded by two engines. I think, however, that most railroad engineers would prefer to adhere to the latter as a standard, and use instead the equivalent uniform loads for all ordinary cases, rather than to adopt a load that does differ considerably in its effects from those loads to which bridges are apparently subjected. I hope that the gentlemen who have advocated the locomotive excess method, and perhaps even some of those who advocated the engine diagram method, will conclude to vote for the equivalent uniform load method after reading my explanations as to what that method really is, and what a great amount of labor it saves.

There is surely no valid objection to a man's changing his opinion; and I think that the remainder of this *résumé* will show that I am quite ready to change mine either when proven in the wrong or when something better than mine is offered. To begin with, in respect to the theory of floor-beam concentrations, I am quite ready to cry *peccavi*, the more so as my friend, Professor Du Bois, lets me down so gently; but, although an acknowledged "sinner," I am by no means a repentant one, for I am well pleased to have made the oversight, because of the attention that has been called to an important fact which was not generally known by the engineering profession.

The Proper Live Loads for Modern Bridge Specifications.—Answering Mr. Thomas H. Johnson, I would state that for roads with comparatively light grades the growths of weights of engines and of cars appear to have kept pace with each other fairly well; but for mountain roads the engine weight is greater in proportion to the car weight than my proposed standards give, hence the said standards would not apply to mountain lines. I fear that the general managers of railroads throughout the United States would at present, and with good reason, object seriously to paying for bridges designed for a car load of 4,000 pounds per linear foot, excepting those on the great trunk lines. My proposed standards give railroad men a choice of loads, and if none of them suit, let their engineers adopt others, but furnish with their specifications diagrams of equivalent uniform loads similar to those given by Messrs. Stites and Treadwell in their discussion. At the same time I believe it would be advisable to modify my standards so as to include loads for mountain lines, but to reduce the total number of standards to a minimum.

It is my intention, when communicating with the chief engineers and bridge engineers of railroads, as mentioned in the beginning of this *résumé*, to consult with them as to what standards they desire, so as to endeavor to prepare a set of standards that will satisfy the large majority of railroad engineers.

On account of certain statements made in several of the discussions, I desire to adopt the following loads concentrated on two pairs of wheels spaced seven feet centers, to be used only for stringers, floor beams and primary truss members with their connecting details, when the panel lengths are less than 15 feet, and to incorporate the results in the diagrams of equivalent uniform loads and of end shears in plate girders.

Class Z	75,000	pounds.
Class Y	80,000	"
Class X	85,000	"
Class W	90,000	"
Class V	95,000	"
Class U	100,000	"

Amounts of Wind Pressure.—I endorse heartily Mr. Lindenthal's remarks to the effect "that the lateral bracing of the bridge is more often and more severely strained by the lateral blows from swiftly moving engines and cars, causing lateral vibration, than from the wind itself," and would suggest that if the series of tests of actual intensities of working stresses hereinafter proposed be carried out, the effects of live loads on lower lateral systems be determined.

Answering Mr. Bouscaren, a pressure of 50 pounds per square foot on the empty structure is, as shown by Mr. Thacher, sufficient to buckle the bottom chords of nearly any single track, pin-connected bridge in this country. It is much better to make the specified wind pressure low and proportion properly, letting the structures take their chance of being struck by a cyclone, rather than to adopt a wind pressure that would necessitate stiff bottom chords for most bridges without giving any assurance of safety from cyclone.

Mr. Osborn is right in stating that it is a nuisance to have to figure the wind pressure on bridges, and that some simple formula ought to be provided. Mr. F. H. Lewis, in a most valuable and interesting paper on "Soft Steel in Bridges," presented to the Engineers' Club of Philadelphia, gives the following: "The bottom lateral bracing in deck bridges and the top lateral bracing in through bridges must be proportioned to resist a uniformly distributed lateral force of 150 pounds per linear foot of bridge for all spans of 200 feet and under, and an addition of 10 pounds per linear foot for every 25 feet increase in length of span over 200 feet." "The bottom lateral bracing in through bridges and the top lateral bracing in deck bridges must be proportioned to resist a uniformly distributed force the same as above, and an additional force of 300 pounds per linear foot of bridge, which will be treated as a moving load." Provided there be no screens or hand-rails, the specification quoted will answer, but otherwise I would prefer to adhere to the method given in my paper.

Answering Mr. Skinner, I would state that it is not customary to consider impact in wind loads, for the reason that the latter as assumed are of rare occurrence, and are ample in every respect.

Effects of Wind Pressure.—Referring to Mr. Douglas' remark, viz., "It does not seem necessary for the railroad company to tell the contractor how to compute the stresses. The latter is supposed to know that"—I would reply that such is exactly what the contractor does need to be told, and in most cases what he wants to be told, as is evidenced by Mr. Cowles' remarks.

Replying to Mr. Hodge, my reason for not considering the transferred load (amounting, as he states, to 300 pounds per linear foot) on the leeward stringer is because such a load is rare, and therefore its effect should not be considered unless the amount exceed, say, 25 per cent. of the live and dead load, which it does not. To be perfectly consistent, however, one should take into account the load transferred to the leeward truss by the wind pressure upon the train in finding the truly greatest stress that can come upon the leeward bottom chord. For single track bridges it will amount to no more than 200 pounds per linear foot, while the transferred load from wind pressure on trusses varies from 300 pounds to 700 pounds per linear foot. This difference between the two transferred loads, however, must be noted: the former acts simply as an increase to the dead load, while the latter causes an increased reaction on the leeward pedestals and a constant stress from end to end of bottom chord, as explained before. Decidedly, the transferred load on the leeward bottom chord from wind pressure on a train should not be ignored.

Styles and Proportions of Bridges.—Replying to Mr. Thomas H. Johnson and Mr. Snow on the subject of pony truss bridges, I would state that while I would not condemn an existing structure merely because it is a pony truss bridge, still I would be quite suspicious of it, and in no case would I design one, unless, perhaps, it be of the style mentioned by Mr. Swift. The general opinion of engineers concerning pony trusses is that their construction should be relegated to the past.

The limiting length of plate girder spans appears to be still a disputed point; and it is evident that railroad engineers and bridge engineers desire to make it as great as practicable, while manufacturers (who have all the trouble of loading, shipping and erecting) prefer to keep it down to about 70 or 80 feet. Mr. Snow's deck plate girder bridge may be a very good one, but it is unnecessarily expensive, as would be discovered by the general manager of any line of road who would try the experiment of building such structures.

Answering Mr. Thomas H. Johnson and others, my reasons for using sub-struts instead of sub-ties in divided panels are:

First.—The former carry the loads more directly to the piers, and

Second.—As they have fully twice the area given to the sub-ties, they permit of only one-half of the deflection of the top chord at the middle of the long panel. As for ambiguity of stress in the counter-braced panels, I would state that it is my custom to proportion all members in and about these panels so that the stress can travel by either the sub-strut or the counter; and I contend that this is good practice, for the reason that the members in such places are generally light enough, in all conscience.

In answer to Mr. Swift's remark concerning thickness of connecting plates in lattice girders, I would state that it is my latest practice to make such plates comparatively thin and large, and to use an apparently excessive number of rivets, connecting both legs of every web angle iron to the plate, and employing, when practicable, the built star section for all diagonals and verticals.

Professor Swain advocates the use of suspended floor beams. In certain cases of very shallow floors they would be advantageous, provided that they be properly stayed and that plate hangers be used. These, however, necessitate pins of large diameter, which may be objectionable in small bridges. As a shallow floor is a feature in bridge designing that it is desirable to avoid when possible, we may conclude that suspended beams should be used in special cases only.

Much to my regret, but little has been said about riveting floor beams to posts. The detail, although it may not be theoretically scientific, is, nevertheless, a good one for beams of ordinary depth. Should in the future the top connecting rivets wear loose, they can be readily replaced, and no harm will be done, provided there always remain an ample number of rivets to take up the shear.

But little has been said about the advisability of increasing clear roadways so as to provide 8 feet between the center line of the nearer track and the innermost portion of the truss. A number of well known railroad engineers have lately expressed to me their approval of the proposed change.

Mr. Buck writes thus: "But there is no economy in attempting to make the bar act as a beam in sustaining its own weight. The nearer it can come to assuming the catenary due to its own weight and the tensile stress upon it, without acting as a beam, the better." I am glad that Mr. Buck has taken this stand, for the point is one that needs attention, and I hope it will soon receive it at the hands of bridge engineers. In my opinion, the idea advanced is erroneous, and I am strongly opposed to the use of long, light, shallow eyebars in bridges, if for no other reason than because of their sag (which is often apparent to the eye) and their vibration.

Mr. Buck states that it is apparently impossible, where eyebars are used for bottom chords, to have the axes of the lateral diagonals pass through the intersections of the axes of posts and chords. Mr. Skinner appears to agree with Mr. Buck in this opinion. Time and space do not permit me to describe here the method of accomplishing this desideratum; but I have in my office drawings for the Pacific Short Line Bridge, which is to cross the Missouri River at Sioux City, Iowa, in which the "focusing of all lines of strain at an absolute point at the center of a main truss lower chord connection" is effected perfectly.

In my opinion, the results given by Mr. Osborn concerning stresses in eyebars because of their own weight, are not satisfactory, for the reason that he has ignored the reverse bending moment, which is equal to the direct pull multiplied by the deflection. Professor Johnson takes this into account, but at the same time makes an assumption which I do not think is warranted, viz., that the deflection v is the same when there is direct tension on the bar as it would be if there were none. My method of setting this point would be to place a number of bars of various lengths and sizes in a testing machine, subject them to various pulls (P), and to measure with great accuracy the actual values of the deflection (v), then substitute for P and v in Professor Johnson's equation 3 and solve for f. My table of limiting sizes of eyebars was determined partially by some rather crude calculations and partially by practical experience and judgment.

There seems to be considerable difference of opinion in respect to the proper spacing of stringers, which would be hard to reconcile; but there is nothing in the discussion to cause me to alter my judgment that the best distance between stringers is 8 feet. Perhaps the ultimate solution of the question will be the entire abandonment of wooden floors and the substitution of corrugated metal with ballast, in which case the distance between stringers would be dependent upon the size and strength of the corrugated plate. The principal objections to this style of floor are its liability to rust and its excessive weight. The latter objection would apply principally to long spans.

Answering Mr. Nichols' question concerning the spacing of guard rails in my proposed floor system, the distance from the center of track to the center of outer guard rail is 4 feet, leaving about 14 inches clear between the head of the rail and the outer guard, and the corresponding clearance for the inner guard is 7 inches. The question as to whether pine or oak should be used for ties and guards is still unsettled, but the general disposition seems to be to favor yellow pine.

I am glad to have my remarks on the exclusive use of steel for bridges endorsed by so high an authority as Mr. Burr, although Mr. Thacher, another high authority, differs with us both on several important points. Mr. Lewis' paper on "Soft Steel in Bridges," before referred to, throws a good deal of light upon the subject. It is to be hoped that the discussion of this important matter will be continued, although if it is not, the effect in my opinion will be only a very short delay in the abandonment of wrought iron for bridges. I am in favor of using medium steel for all parts of bridges, excepting for rivets, for which I would use soft steel. Answering Messrs. Gates and J. M. Johnson, I would state that I failed to specify the grade of steel for two reasons; first, medium steel was understood, as that is what nearly all bridge builders are now using; and, second, my paper was not intended (and, in fact, was not permitted) to be a specification.

Intensities of Working Stresses.—In respect to this subject it appears that we are all at sea; and we are liable to remain there until such time as the much needed experiments on actual intensities of working stresses, that I have been advocating for years, be made, after which we shall be able to settle upon a system of intensities that will be logical. Meanwhile we shall have to jog along in the best way that we can, letting each engineer use his own judgment concerning the intensities to employ, or perhaps (which is the best thing to be done under the circumstances) obtain a consensus of opinion as to what system to adopt for a temporary expedient. The method adopted by Mr. Schneider, of reducing all live load stresses to their equivalent static stresses before applying a constant intensity, is undoubtedly the scientific way to proportion bridges; but until we have some real knowledge of the effects of dynamically applied loads, it does not seem advisable to develop a system that in all probability will have to be considerably modified in the future.

It would not be such an immense undertaking to make an exhaustive series of tests of the effects of live loads applied to bridge members with varying velocities. Perhaps a year's time and an expenditure of, say, $50,000 would suffice. If not, more time and money should not be begrudged upon such an important matter. The United States Government is willing to appropriate annually millions of dollars for the United States Engineers to use in experiments upon hydraulic problems. Why cannot the bridge engineers and the railroads obtain from Congress a small appropriation to decide one of the most vital questions in bridge building? If the United States Government refuse to make such an appropriation, cannot one of America's millionaires be persuaded to donate the money as a contribution to applied science?

In my opinion the proper steps to take after obtaining the money would be as follows:

First.—To appoint a committee of seven members of the American Society of Civil Engineers, who are acknowledged bridge experts, to act as an advisory board, and let them lay out the series of tests (to be modified later if they should think advisable), appoint a committee of three well-paid expert bridge engineers to make the tests under their instructions, attend to all payments of money, make arrangements with railroad companies for the use of their lines and bridges in making the tests, etc.

The first practical step to take would be to investigate all the machines thus far invented for measuring extensions and compressions in bridge members, so as to decide upon what kind of apparatus to adopt or to design new ones if necessary. These machines should be tested thoroughly to determine their accuracy as far as static loads are concerned and to prove their reliability in case of dynamically applied loads. After the machines are shown to be satisfactory, experiments should be begun systematically upon all parts of bridges of modern design, with trains varying in velocity from zero to the greatest attainable speed. Sufficient tests of all kinds should be made to give good average results. Both tension and compression members should be experimented upon, and if the machines prove to be very accurate, even such intricate problems as the distribution of stress in plate girders might be solved. This field of experiment is most inviting, especially because of the great utility of the results; hence there would be no difficulty in obtaining an expert committee to make the tests. Mr. Woelfel's remarks on the subject of measuring the actual intensities of working stresses are most interesting, and are worthy of a careful perusal.

Next to the series of tests just described, the most needed experiments are some on steel, especially in full size compression members of all kinds. A systematic effort on the part of the members of the American Society of Civil Engineers ought to secure this also. If we had the results of such a series of tests, we should be able to make diagrams giving working intensities for all kinds of compression members, and thus avoid all difficulty due to numerous and varied formulæ. Now on account of these reasons I do not consider it either advisable or in any way beneficial to discuss theoretically the proper intensities of working stresses or column formulæ, consequently I shall take no further notice of several elaborate mathematical dissertations that are to be found in the discussions.

Mr. Thomas H. Johnson objects for æsthetic reasons to the use of stiff bottom chords near the ends of spans. Such struts in most single track bridges are a necessity, hence "a due regard for the eternal fitness of things" would cause their adoption, even if "the change from eyebar to the built form is an offense to the eye." It is not good engineering to sacrifice excellence to mere appearance, and I do not think that any portion of a design which gives *prima facie* evidence of its use can be cause of offense to the eye of an engineer.

Mr. Johnson objects to my top chord formula, stating that for $\frac{L}{r} = 50$ it is 27 per cent. too high, and at $\frac{L}{r} = 120$ it is 16 per cent. too low. He says that the formula is utterly without support in reason or experience, and is a purely arbitrary assumption in every particular. That it is an "arbitrary assumption" I grant, but in respect to the other assertions I beg to differ with the gentleman. For values of $\frac{L}{r}$ not exceeding 50, it is customary with some engineers to strain steel compression members a certain fixed amount based upon the corresponding intensity used for tension members. Mr. Bouscaren, whose standing as a bridge engineer neither Mr. Johnson nor any one else will be disposed to question, strains short compression members 12,000 pounds per square inch, where he strains the corresponding tension members 14,000 pounds per square inch. My intensities for compression and tension are in the ratio of 11,000 pounds to 12,000 pounds, which is different, it is true, from Mr. Bouscaren's ratio, but not so very different. As for my formula giving results 16 per cent. too low for cases where $\frac{L}{r} = 120$, I wonder why Mr. Johnson did not assume $\frac{L}{r} = 500$ in making his comparison! Who ever heard of $\frac{L}{r} = 120$ for the top chord of a railroad bridge? It scarcely ever exceeds 65 in the lightest structures, and even in inclined end posts it goes no higher than 85. The fact that my formula discourages the use of large values of $\frac{L}{r}$ is a point in its favor. Moreover, until we know more about the resistance of steel columns, it is probably as good as any other, and is just as likely to be correct.

Answering Professor Swain, I would call his attention to the fact that I use the form of the fatigue formula merely as a compromise until something better and more reliable can be established. I agree with Professor Swain that the sudden change in intensity for flanges of plate girder spans at a length of 20 feet is not scientific; but I adhered to it, first, because it is to a certain extent customary; and, second, because it tends to discourage the use of short panels. Professor Swain is in error when he states as follows: "And surely the allowable stress for chords in a truss 500 feet long could be greater than for chords in a truss 100 feet long on account of the difference in impact, *although by Mr. Waddell's formulas the same would be allowed in both cases.*" (The italics are mine.) He must have forgotten that the dead load per foot for a 500-foot span is much greater than that for a 100-foot span, while the live load per foot in the former is less than that in the latter. For these two reasons $\frac{\text{min. stress}}{\text{max. stress}}$ for the 500-foot span is much greater than it is for the 100-foot span. Referring to some of my office records, I find the following:

For a 100-foot span, dead load = 1,200 pounds.
live load = 3,300 pounds.

$$\therefore \frac{\text{Min. stress}}{\text{Max. stress}} = \frac{1,200}{4,500} = 0.226.$$

For a 500-foot span, dead load = 4,000 pounds.
live load = 3,500 pounds.

$$\therefore \frac{\text{Min. stress}}{\text{Max. stress}} = \frac{4,000}{7,500} = 0.533.$$

The corresponding intensities for bottom chords are 13,356 pounds for the 100-foot span and 15,198 pounds for the 500-foot span.

Respecting Mr. Bland's remarks upon the New York Elevated structure, is it not evident to any bridge engineer who rides over some of the older lines that they are wretchedly designed, especially in details? This is probably the reason that they begin to show signs of failure. One of my favorite axioms, viz., that "two rivets do not make a connection," appears to be violated constantly in these structures.

I desire to correct a small typographical error which, in spite of all care, crept into my paper. The formula for lateral struts should read

$$p = 17,000 - 65 \frac{l}{r}$$

instead of

$$p = 17,000 - 55 \frac{l}{r}.$$

Combined Stresses.—Concerning the fixedness of inclined end posts at pedestals there appears to be a difference of opinion, and there is reason on both sides. I am ready to concede that with a heavy end floor beam rigidly attached to the inclined end posts, the conditions are much better than those for the assumed free ends; but, on the other hand, the end floor beams are not very thoroughly riveted to the inclined end posts, there is play in the pin hole, and the anchor bolts do not hold down the expansion pedestal very firmly. Perhaps after all I do not differ in effect essentially from Messrs. Burr and Swain, because, while I use a long lever arm in finding the bending moment, I strain the metal on the extreme fiber very high; and they use a short lever arm and probably strain the metal much lower.

Answering Mr. Bouscaren, my reasons for straining metal in inclined end posts so high are as follows:

1st. My assumed lever arm is really greater than necessary in a well designed bridge, although I believe with Mr. Bouscaren that it is never twice too great. 2d. The great intensity is on the extreme fiber only, while the average over the whole section does not greatly exceed that allowed for live and dead loads. 3d. The member under such an intensity is essentially a beam rather than a strut, consequently it can be strained higher. 4th. The wind loads assumed are greatly in excess of those that are ever likely to come upon the structure. 5th. The combination of greatest live load and greatest wind pressure is highly improbable. 6th. Even if the extreme fiber stress should ever reach the limit, no harm would be done, although it would not be advisable to make a practice of straining metal to such an extent.

Time and space will not permit me to give Mr. Skinner the proof of how the addition of 17 square inches to the section of a bridge member can "increase the working strains so enormously as 18 per cent.," but if he will investigate mathematically for himself the two cases following, I think he will become convinced of its possibility.

1st. Take an eyebar 1 x 6 inches, with pin holes on its axis, and strain it 60,000 pounds. 2d. Add at one edge of the eyebar, metal 1 x 6 inches, thus forming a 1 x 12-inch bar, and apply the same stress of 60,000 pounds, but do not change the position of the eyes. 3d. Compare the extreme fiber stresses in the two cases. Mr. Fulton's remarks concerning wind stresses indicate that he is not in accord with modern American practice, for surely it is proper to strain metal higher for a combined live, dead, and wind load than for a combined live and dead load.

Plate Girder Proportioning.—Answering Prof. Swain, my practice is to use at least four vertical rows of rivets, spaced three inches, with two three-eighths x 12-inch splice plates at each web splice, and in addition for each flange two long, narrow plates, one on each side of the vertical legs of the flange angles, to compensate for the divided web at the place where compensation is most needed for bending.

Mr. Snow desires my reason for the following statement: "Of course if the web be counted in, the intensities of working stresses of the flanges will have to be decreased accordingly." It ought to be evident that if we design a plate girder for a flange stress of 10,000 pounds per square inch, ignoring the aid of the web in resisting bending, and consider it to be properly designed, it would not be correct to redesign the girder by a formula that provides for relying upon the assistance of the web in bending, without making the working intensity less than 10,000 pounds. Otherwise we would find a smaller flange area than was found for the first design. This is a point that has often been taken advantage of in competition.

The preceding explanation will answer also Mr. Hutton's first remark. In answer to his second, I would state that relying upon the web to resist bending does not militate against its resisting the shear. In answer to his fourth remark, I would urge that I have not been "a partisan of the flange-only-for-bending theory in its most extreme applications" (even so far back as ten years ago), as my work on "The Designing of Ordinary Iron Highway Bridges" will testify; but have acceded of late years to general custom, knowing that the results of the two methods do not differ essentially, when the formulas are properly adjusted. Mr. Hutton evidently has in mind a decision of mine respecting an existing structure supposed to have been designed in strict accordance with certain standard specifications that ignore the resistance of the web for bending. Of course I had to be governed by those specifications in making my report.

In reference to Mr. Douglas' remarks concerning the moment of inertia formula for plate girders, I willingly concede its greater exactness; but for all ordinary cases the approximate method will give sufficiently accurate results and save considerable time in computing. Such a girder as Mr. Douglas instances is abnormal, although circumstances may occasionally call for its use. Economic considerations require that the weight of the flanges should be about equal to that of the web and its details, and a girder designed according to this rule will always give a depth sufficient for stiffness. For long spans other considerations than economy control the depth. It might be well to specify that whenever the area of the flanges exceeds that of the web by more than 50 per cent. the exact formula be used, and in other cases the approximate one.

I am glad that Mr. Osborn has called attention to Mr. Thacher's neat and expeditious method of computing lengths for cover plates by means of the slide rule; for I am a firm believer in the use of that instrument as well as of all other labor saving devices.

General Details of Construction.—Mr. Gayler is right in placing the minimum thickness of metal in railway bridges at three-eighths of an inch; and in my opinion it is only a desire to comply with the wishes of those who pay for the structures, which prevents engineers from adopting this limit.

In regard to the reaming of steel, I am quite ready to be convinced of my error by a general consensus of opinion; mine on this point, I must acknowledge, is mostly second-hand. It is evident that reaming is a good precaution; but the question is, "Is it worth the cost?" If it be decided that medium steel should be reamed, I think that wrought iron also should be required to receive the same treatment. Mr. F. H. Lewis' paper on "Soft Steel in Bridges" sheds much light on this subject; but I think that a further discussion of it by those who are most competent to give an opinion would be of great value.

An extended series of experiments is needed to determine the proper lengths for stay plates. I, as well as all the bridge engineers with whom I have discussed the subject, believe that Mr. Bouscaren's requirements are excessive, especially in large bridges; but upon the subject of latticing I agree with the remarks made by that gentleman.

Conclusion.—In bringing this *résumé* to a close, I desire to enumerate the results which, I hope, will be accomplished by this paper and the discussions it has evoked.

First.—The abandonment of the engine diagram or concentrated load method of computing stresses, except for unusual cases such as multiple systems of cancellation; and the adoption of the method of equivalent uniform loads.

Second.—The adoption of certain standard engine and train loads.

Third.—An exhaustive set of experiments to ascertain the dynamic effects of live loads applied at various speeds on bridge members of all kinds.

Fourth.—An elaborate series of tests of full-size members of steel bridges, especially compression members of all kinds.

Fifth.—Ultimately, the adoption by the profession of standard specifications for bridge designing, which shall specify clearly and concisely in every particular such important matters as loads, intensities of working stresses, quality of materials, workmanship, etc., but at the same time shall not infringe upon the individuality of the designer.

To the attainment of these ends, it is my intention to devote all the time which I can spare from my practice; and I herewith invite the co-operation of all American bridge engineers and railroad engineers, fully recognizing the fact that one engineer unaided can accomplish practically nothing, but that, with the hearty assistance of his professional brethren, there is nothing in reason that cannot be effected. Finally, I would suggest that further discussions of this paper with its discussions and the *résumé* are in order, and that they can be published in later issues of the *Transactions* of the American Society of Civil Engineers.

COMMENT.

The discussion given Dr. Waddell's paper by the various members of the Society is so full and varied that further comment might seem superfluous were it not for the facts that twelve years have elapsed since the paper was written, and that great changes have taken place in many phases of the subjects under consideration. The increase in the weight of rolling stock alone has caused large modifications in the methods of proportioning those parts of the structure which do not carry direct stresses, such as lateral bracing, portals, transverse sway bracing between posts, and the bracing between the stringers; for when heavier loads than they were designed to carry were placed upon the bridges built ten or twelve years since, it was quickly discovered that these members were unable to resist the great vibrations caused by the increased and rapidly moving loads. It was found that the life of a railway bridge depends quite as much upon the strength and rigidity of these members and upon scientifically designed details as upon the sufficiency of the main members. Within the editor's experience many a railway bridge has been taken down and replaced with a new and heavier structure that would have been considered perfectly safe, notwithstanding high stresses in the main members, if the details had been adequate and the portals and lateral bracing more rigid and more satisfactorily connected. No procedure has proved to be more unscientific and expensive than to provide connections for the lateral bracing just sufficient for the calculated wind stresses instead of those adequate to develop the strength of the section.

Portals and transverse struts between the chords in which the ratio of the radius of gyration to the length is large may be ample to resist wind stresses, yet wholly inadequate for the purpose they were intended to serve; for they are flimsy, and the vibrations set up by a heavy train moving rapidly over the bridge soon loosen the rivets and render the structure unsafe.

In fact, it will rarely be the insufficiency of the main members that will cause the condemnation of a bridge when it is subjected to heavier loads than it was designed to carry. The pennywise plan of providing details just strong enough for the normal stresses is extremely expensive in the end, for the actual but indeterminate stresses due to impact and vibration affect the details much more than the main members. Fifty per cent. excess in the details is none too much, yet few railway specifications demand any at all except in the heads of eye bars and in counters.

Notwithstanding the commonly expressed opinion that rolling stock has reached the maximum limit of weight, the question of provision for a further increase is as much alive as it ever was. At the time the paper on Disputed Points was written, no one ventured to predict that heavier loads than Cooper's Class "A" need be provided for, and very recently the use of Cooper's Class "E-50" was generally thought to make ample provision for the future; but the number of engines which exceed in weight the Class "E-50" engine is rapidly increasing, and ore trains now in use on some Western roads already exceed the E-50 train load about 20 per cent. One of the large steel manufacturers has recently constructed a number of one-hundred-tons-capacity ore cars for use about its plant. If these cars prove advantageous and economical, the use of similar cars will undoubtedly be extended over the ore-carrying roads at no very distant date.

It is unsafe to predict how much further the loads will be increased, hence it is a wise railway engineer who provides for details which will be safe when the main members are largely overstrained. Rigidity is quite as important as strength, notwithstanding the idea sometimes followed that resilience is a satisfactory substitute.

As the railway companies have become more wealthy and have learned to appreciate the advantages of the more expensive permanent structures over those involving low first cost of construction and immediate dividends with high charges for renewals and repairs, typical loads which correspond substantially in distribution but far exceed in weight the heaviest rolling stock in use have been generally adopted. The sole purpose of this action is to provide an excess of strength in bridges and trestles. There is no thought that the exact stresses these typical loads would cause will ever be produced in the structures, consequently, the desire for extreme accuracy (the only good reason for demanding that the engine diagram be used in calculating stresses) is not a *desideratum,* and there is small doubt that an equivalent uniform load would commonly be specified if railway engineers generally understood how closely its results correspond with those of the typical engine loading.

Every engineer is obliged to struggle against a desire for extreme accuracy in calculations and for absolute instead of approximate results, and the railway engineer is no exception to the rule; but the chief reason why he adheres to the laborious engine diagram method of calculating stresses in bridges is that he knows it to be accurate and his judgment is trained in its use. He can ill spare the time to investigate for himself the accuracy and convenience of the equivalent uniform live-load method and to train his judgment anew. hence he continues in the old course and lets the burden it involves fall upon his assistants or the bridge company's computers. Dr. Waddell has demonstrated, other engineers also, that the equivalent live load method saves much labor and is sufficiently accurate for all practical purposes, but the force of habit prevents its general adoption.

Again, the side use of Cooper's specifications and the adoption of his standard typical loadings by the American Bridge Company and by many railway companies, has reduced the labor of preparing engine diagrams and tables of moments and shears to very small proportions, and these conveniences eliminate a large part of the computations to which Dr. Waddell so justly took exception. With such tables at hand the calculation of I-beam and deck plate girder spans and stringers is a very simple matter, and the computation of the stresses in trusses with parallel chords is not extremely laborious, but the labor required to determine the stresses in half-through plate girder spans and in trusses with curved top chords and subdivided panels is inordinately great.

If there were any good, sound reason for retaining the engine diagram method, there should be no complaint on the part of any engineer, for satisfactory results must be obtained at any cost, but, in the absence of such a reason, it is difficult fully to account for the persistence of the more laborious method.

In regard to the styles and proportions of bridges, it is surprising what small changes time has wrought. The Pratt, the Petit, and the Warren trusses continue to be the general favorites. The use of the pony truss has been substantially discontinued, except in highway bridges, but the Warren truss with a double or triple system of cancellation has come into general use on a number of prominent railways. No economy is claimed for it, in fact, it is not quite so economical as the ordinary Pratt truss; but it is thought to be less liable to destruction in case of accident. Great publicity was given to an accident on the Chicago and Northwestern Railway, in which several web members of a double-intersection Warren-truss bridge were damaged or destroyed by a head-on collision without causing the failure of the bridge. It is true that similar accidents have occurred on Pratt truss bridges with equally satisfactory results, but they have not been given similar publicity, therefore a number of engineers are employing the multiple intersection Warren truss, chiefly because they have been led to consider it more safe. The riveted Pratt truss would appear to be quite as satisfactory in this respect, however, for in any truss, when the web member is destroyed, the shear must be carried by the chords in bending. Near the middle of the span where the shear is small and the chords are large, the unusual load should not ordinarily cause failure of the structure, especially if the accident be a head-on collision and the span be nearly uniformly loaded. The Pratt truss with its heavier web members is, of course, freer from vibration than the multiple-intersection Warren, and is also less difficult to erect, consequently, its general use needs no other justification.

The length of span for which the plate girder is used has increased notably of late years, for spans one hundred feet or more in length are not uncommon. Long girders may be handled in the better equipped bridge shops with reasonable economy, but they are difficult to load and troublesome to erect. Unusual care must be exercised to see that there is sufficient clearance in tunnels and bridges to permit shipment of unusually long and deep girders, for the expense of getting past obstructions would be very great.

Long plate girders should invariably be supported by rockers, otherwise, the deflection under load will cause the pressure on the masonry to be distributed unequally. The result will be a crushed bridge seat and stresses in the girder which it was not designed to resist.

Well designed plate girders of great length are but very slightly more expensive of metal than riveted trusses, and the small amount of field riveting they require makes them more economical to erect, consequently, their use is gradually extending. Owing to the excess of metal in the web, they are better able to resist shock than lighter articulated structures, and their form makes it easy to keep them well painted, consequently, they are the most durable of steel bridges.

The half-through plate girder bridge is a thoroughly satisfactory structure, if the distance between the girders be made sufficient to admit, without encroaching upon the clearance, good floor beam brackets which will afford effectual lateral support for the top flanges. Too often considerations of economy of both metal and masonry lead the engineer to leave the top flanges with very inadequate support. The one-time common practice of economizing metal by dispensing with a floor system and resting long ties on angles riveted directly to the girder webs, or even on the bottom flange of the girders, has happily fallen into disuse, though it is still to be seen occasionally. Such loading puts heavy torsion on the web or flange of the girder, and thus increases the stresses enormously above those for which the girder was calculated. Heavy steel trough flooring extending very close to the girder web and substantially attached is, however, free from these objections.

Three-girder spans for carrying two or more tracks should be avoided because the middle girder, being designed for a full load on all tracks, is heavier than the outside girders and will not deflect as they do when the tracks on only one side are loaded, consequently the floor system and its connections are subjected to heavy stresses which they were not designed to resist.

The pony truss for railway bridges has happily fallen into oblivion. Its top chord was rarely well stayed and was often subjected to severe and unknown stresses, while the economy involved in its use was very small.

The fatigue formulæ for proportioning bridges are reluctantly but surely being abandoned. The most prominent railway in this country still uses a modified fatigue formula and a few others have only recently abandoned it. Impact formulæ are much more logical and consequently are rapidly coming into general use. In addition to the simplification of calculations, the impact formula is undoubtedly correct in principle and provides additional metal in the right members. That the additions the impact formula makes to the live load stresses are closely in accord with those actually produced by the moving load, is by no means so certain, but the published results of extensometer tests and those which were made during the editor's engagement with the Baltimore and Ohio Railroad Company indicate that the formulæ most commonly used give results which are approximately correct. Some of the railways have provided themselves with the necessary instruments, and it is to be hoped that they will soon make enough well conducted tests to determine what is the correct impact formula. This is certainly a matter of very large importance to the railway companies, and scientifically conducted investigations along these lines will be worth far more to the companies than they cost.

The intensities of working stresses to be employed are largely a matter of judgment. So many factors enter into the consideration of each case that there is much room for difference of opinion, yet the leading bridge engineers do not differ greatly in their practice. The dead load stresses are easily and certainly obtainable, the stresses caused by the moving loads when they are applied gradually are also determinate; but the stresses produced by impact and vibration are not obtainable with great certainty, the frequency with which the live load will be applied is not known, the amount and frequency of wind stresses are largely conjectural, temperature stresses are commonly neglected, and initial stresses due to imperfections of fabrication and erection are absolutely unknown. The ultimate strength and the elastic limit of the metal vary greatly with the chemical constituents, the temperature of the metal during manufacture, and the amount of work it receives. Incipient cracks may be caused by punching or shearing, and the straightening rolls or the gag-press must, of necessity, strain the metal beyond the elastic limit. The majority of these factors will always be indeterminate, but, with a better knowledge of impact stresses and careful inspection of both the manufacture of the metal and the fabrication of the structure, the engineer will be able to adopt such unit stresses that he will obtain the greatest possible economy which is consistent with safety and durability. The provision for wind stresses in conjunction with the dead and live load stresses will always be difficult to determine, because our knowledge of the intensity of wind pressures and the area over which a given pressure acts is exceedingly limited.

Though it is not difficult to determine what pressure the wind may exert upon very small areas, such knowledge is not of great value, and it is substantially impossible to determine by experiment the intensity of wind pressure over large areas.

The effects of the wind are undoubtedly very great, especially in exposed positions and in deep, narrow valleys, which act as chimneys. The infrequency of very high winds warrants the adoption of large unit stresses to provide for them, but the indirect as well as the direct stresses should be considered.

The transferred load due to wind is too often neglected entirely. It is generally of small moment on girders and short spans, but its importance increases rapidly with the length of span.

Ample provision is generally made for the stresses resulting from the centrifugal force of the moving trains, though the load it transfers to the outside girder or truss is commonly neglected. This is of small importance on trusses and main girders, but the proportionate overload sometimes becomes very high on the closely spaced stringers of through plate-girder spans, where, in the editor's opinion, provision should be made for it.

Dr. Waddell's paper and the discussions following it have served an excellent purpose in bringing into prominence and establishing firmly many points which were known to a few but were not in general use. For instance, the discussion makes it apparent that a few engineers were acquainted with and made use of the fact that the position of the loads which will produce the maximum bending moment at the middle of a span of twice the panel length will also produce the maximum floor beam concentration, but the fact was not generally known and was, consequently, of small service to engineers. Prof. Du Bois in his discussion points out that the fact is a corollary of a well-known law, but it is quite evident from the comments of other engineers that it had rarely been deduced.

Rules governing the dimensions of the various types of spans and of their principal members must of necessity be of general application only, since the conditions upon which they are based are ideal and rarely attained in practice, but, if they are correctly established, the closest possible adherence to them will be productive of the best results attainable. In replacing the superstructures it will often be found best to depart somewhat from theoretically correct proportions in order to avoid alteration or reconstruction of the masonry or to maintain the old structure during the construction of the new. For these and similar reasons the engineer's judgment frequently demands that he deviate from rules and standards; but they form an excellent base, even in extraordinary cases. Well established rules often appear to be very arbitrary, but investigation will generally demonstrate that they are the resultant judgment of many well-informed men.

The distance between the central planes of bridge trusses is fixed by the dimensions of the end posts and the established clearance in through bridges of short span. Most of the railways in the United States agree in demanding fourteen feet clear width for single-track bridges, and, as the extreme width of the rolling stock exceeds ten feet very slightly, this seems to make ample provision for possible projection of the load beyond the car and for the safety of trackmen. In double-track bridges the clearance varies with the distance between track centers. This is commonly twelve feet, but many roads are now wisely increasing it to thirteen or fourteen feet. For spans of considerable length, however, the distance between trusses must be governed by the overturning moment of the wind, the effect of the transferred load, the direct wind stresses in the chords, and the cost of the floor and lateral systems, and occasionally by the cost of the masonry. At the present time, however, engineers generally agree that this distance should not be less than one twentieth of the span.

The theoretically economical depth of truss may readily be determined mathematically, but within considerable limits this depth may be varied at immaterial expense of metal. The overturning moment caused by the wind, the difficulty of handling very long web members, and especially the high cost of the traveler make it advisable, however, to select a depth of truss well below that which the economy of metal alone would dictate. Frequently in the case of very long spans material expense can be saved by varying the depth so as to admit the use of a traveler already in the possession of the bridge company.

Too much stress cannot well be laid upon the necessity for ample, rigid, and well-connected lateral systems, for the life and safety of the structure are more largely dependent upon them than the determinable stresses indicate. It is still very commonly customary to provide only enough rivets to care for the wind stresses, even though to develop the strength of the section of the lateral member would require double the number. In this way the stresses set up by vibration and the thrust of the train are wholly unprovided for when the assumed wind load is in action and are inadequately provided for in any event. It is small wonder, then, that loose laterals are very common. It is hardly necessary to add that the swaying of the locomotive makes essential a good lateral system between the stringers.

The use of rods for lateral members of railway bridges is entirely indefensible in this day when the superiority of shapes in small structures and of built members in large ones has been so thoroughly demonstrated.

The danger of serious accident from derailment where the floor and guards are adequate has proved to be so small that very few of even the most substantial railroads have considered the cost of safety stringers outside the main stringers justifiable. When such stringers are employed they are calculated to carry the derailed load, though the unit stresses are double those used for the principal stringers which are placed immediately under the rail. Two stringers spaced six and one-half or seven feet from center to center, together with a satisfactory floor, furnish ample provision against accident and do not involve unnecessary expense, consequently this is the arrangement generally adopted.

One of the avowed purposes of Dr. Waddell's paper was to bring the designing of railway bridges toward a standard which should be acceptable to bridge engineers generally. A reasonable approach to standards in engineering practice is undoubtedly very desirable. What is unquestionably good in the practice of the best specialists in any particular branch should be widely known and used in order that the casual work of specialists in other branches and the designs of younger men may be improved. Dr. Waddell's writings have contributed enormously to this end and are in consequence widely appreciated by the profession. But to carry standardization to the extreme, and confine all work to set formulæ would be fatal to growth and certainly is not to be desired, and most assuredly such a result was not one of the objects sought when Dr. Waddell prepared this paper and presented it for discussion.

By common consent hung floor beams, pony trusses, Whipple trusses, lateral rods, stringers resting on top of floor beams, and lateral systems lying well out of the plane of the chords have been abandoned by engineers of repute; and adjustable members in trusses are rapidly becoming obsolete. Wooden blocks between the base plate and the masonry and cast-iron pedestals have been abandoned. Newly constructed three-truss double or quadruple track spans and three-post bents are very rare. All these alterations in practice are evidence of the interchange of ideas among bridge specialists and of the tendency toward standardization. Many less important details have also been brought into common use, but the idea one hears expressed occasionally that railway bridges are now so nearly standard that it does not require a high order of engineering skill to design them was never farther from the truth. It is true that the data available in engineering literature and a moderate experience will enable any educated engineer to prepare satisfactory plans for the more simple structures to be used where conditions are normal; but the design of large structures, the highest economy of metal consistent with strength, the development of new materials and of new processes of fabrication and erection, and increased train speeds, and weights constantly present new problems the solution of which requires the highest available talent, and the growth in the science and art of bridge building depends upon the ablest bridge specialists. Mediocre men follow custom and reproduce good things at small expense, but they often fail through their inability to determine the applicability of certain structures to given conditions. There are copyists in the sciences as well as in the arts, and their work is as easily distinguishable in the one case as in the other.

THE COMPROMISE STANDARD SYSTEM

OF

LIVE LOADS FOR RAILWAY BRIDGES

AND

THE EQUIVALENTS FOR SAME.

INTRODUCTORY NOTES.

In the paper entitled *Some Disputed Points in Railway Bridge Designing* which Dr. Waddell presented to the American Society of Civil Engineers early in 1892 he proposed a system of live loads for railway bridges and suggested a method of calculating equivalents for them which could be used as uniformly distributed loads in computing the stresses in bridges. Though many other points relating to railway bridge design were brought forward in this paper, its discussion was devoted chiefly to these proposed loads and method of computation. This general interest in the matter led Dr. Waddell to continue his efforts to induce bridge engineers and railway engineers to abandon the uselessly laborious methods of calculation and to adopt one simple and adequate system of loadings. November 19, 1892, he sent to every Member of the American Society of Civil Engineers who was interested in railway or bridge work a ballot, and asked for a vote for or against, 1st, abandoning the wheel load method and adopting the equivalent uniform load method of computing stresses; 2d, adopting a system of standard engine and train loads; 3d, having made exhaustive tests to determine the dynamic effect of a moving train on bridge members; 4th, having made thorough tests of full-size members of steel bridges; and, 5th, the ultimate adoption by the profession of standard specifications for railway bridges. The number and character of the replies were eminently satisfactory; consequently, May 13, 1893, a circular letter containing a statement of the results of the ballot and a further explanation of the proposed standard system of loads and their equivalents was sent to the principal railway and bridge engineers of the country. A ballot accompanying this letter asked for a final vote for or against, 1st, the adoption of the "Compromise Standard System of Live Loads for Railway Bridges" when having plans prepared or when calling for bids on railway bridges, and, 2d, the adoption of the "Equivalent Uniform Load Method" of computing stresses. More than one hundred chief engineers of railroads agreed to adopt for their work both the "System of Live Loads" and the "Equivalent Uniform Load Method"; consequently Dr. Waddell prepared and published late in the summer of 1893 the pamphlet which follows.

Before the pamphlet appeared the result of the first ballot was communicated to the *Engineering Record* in a letter dated June 3, 1893. Simultaneously with this letter the *Record* published an editorial relating to it, criticising the "Equivalent Uniform Load Method" and advocating the use of a uniform train load both preceded and followed by either a single or a double excess load which would produce stresses substantially equivalent to those of the actual wheel loads.

A rather spirited controversy followed. Evidently the editor of the *Record*, like many another accepted authority, based his criticism upon his personal preference and experience, rather than a study of the question at issue, and expected his editorial position to lend finality to his statements. But in this case he "reckoned without his host," for Dr. Waddell replied with figures and completely established the fact that the Equivalent Uniform Load Method produces more accurate results with much less labor than either the Single Excess or the Double Excess Method. The *Record's* editor softened his defeat by cutting out of Dr. Waddell's last letter some of the more pungent paragraphs, but time has demonstrated the incorrectness of his position, even if Dr. Waddell had not done so. for both the Single Excess and the Double Excess Methods have dropped entirely out of use.

The letters above mentioned and the *Record's* editorials are reprinted here because the letters especially contain a better description than is given elsewhere of the methods of deriving and using the equivalents for the Compromise Standard System of Live Loads, and demonstrate clearly the high degree of accuracy obtained by the Equivalent Uniform Load Method. They also contain some demonstrations of the case with which computations may be made by the Equivalent Method as compared with the wheel load method, but it hardly seems necessary to prove to trained engineers that the use of a uniform live load involves the least possible labor of computation.

The fact that the wheel load method of computing stresses in railway bridges remains in very general use to-day is not at all complimentary to the railway and the bridge engineers of the country; for it must be attributed chiefly to their failure to understand the degree of accuracy obtainable by the Equivalent Uniform Load Method. It is true that a comparison of the stresses computed by the two methods and the derivation of the equivalents are not generally available, for they have been published only in "Some Disputed Points" and in these letters; but Dr. Waddell's advocacy of the Equivalent Method should be sufficient reason for a thorough investigation of a device which will manifestly save a great deal of labor, and investigation would commonly carry conviction with it. Some reason for the continued use of the laborious process is no doubt to be found in the ease with which an engineer may explain to officials who lack technical training that the bridges are being designed to withstand the exact stresses produced by a typical engine and car load. The layman is not a good judge of the degree of accuracy desirable, and his confidence is shaken by anything less than the absolute. He is not in position to understand the many other approximations used in designing a bridge, but concentrates his attention upon the stresses produced by the moving load. Consequently, engineers continue to satisfy his demands, those of the bridge companies for commercial reasons, those of the railway companies for reasons of policy. The saving of labor by using the Uniform Load Method may be indicated

THE COMPROMISE STAN
OF
LIVE LOADS FO

the loads which were used in obtaining the data for plotting the curves on sheets 2,3,&4.
For finding stresses use the equivalent loads given by said curves.

by the fact that Dr. Waddell once figured the live load stresses in a 624-foot span in 49 minutes, those in a 524-foot span in 29 minutes, actual time.

It is clearly demonstrated in the succeeding pages that the accuracy of the Equivalent Uniform Load Method is all that can be desired; and every engineer knows that after laboriously calculating with great exactness the stresses produced by a load which has been assumed and which will never be closely approximated in practice, he must make further assumptions regarding the value of his metal and the effects of impact and vibration which may be far from the truth; consequently, it is to be hoped that the simple and rational method of computing will ultimately obtain.

And the editor believes that Dr. Waddell's work will contribute largely to that end. The great reduction in the number of loadings specified nowadays may with due modesty be attributed largely to his paper on "Disputed Points." Dr. Waddell has spent money, his own time, and that of his assistants in the preparation and publication of the succeeding pamphlet in the hope that engineers might be saved useless labor. In the second edition of *De Pontibus* he extended the system of loads and equivalents to correspond to the recent increase in the weight of rolling stock; and it seems that still further extensions will be necessary to meet the requirements indicated by Mr. Henry W. Hodge in his recent address to the International Engineering Congress at the Louisiana Purchase Exposition.

Engineers are rapidly coming to understand that the men who are the most successful are not the pure technists or the men who spend great effort upon non-essential matters, but those who take a broad view of their profession; men, who, without sacrificing principles or essential details, draw broad conclusions and eliminate all labor which does not produce useful results. Hence it is to be hoped that veneration for a custom will soon give way to good judgment and admit to general use the simple and eminently satisfactory Equivalent Uniform Load Method of calculating the stresses in railway bridges.

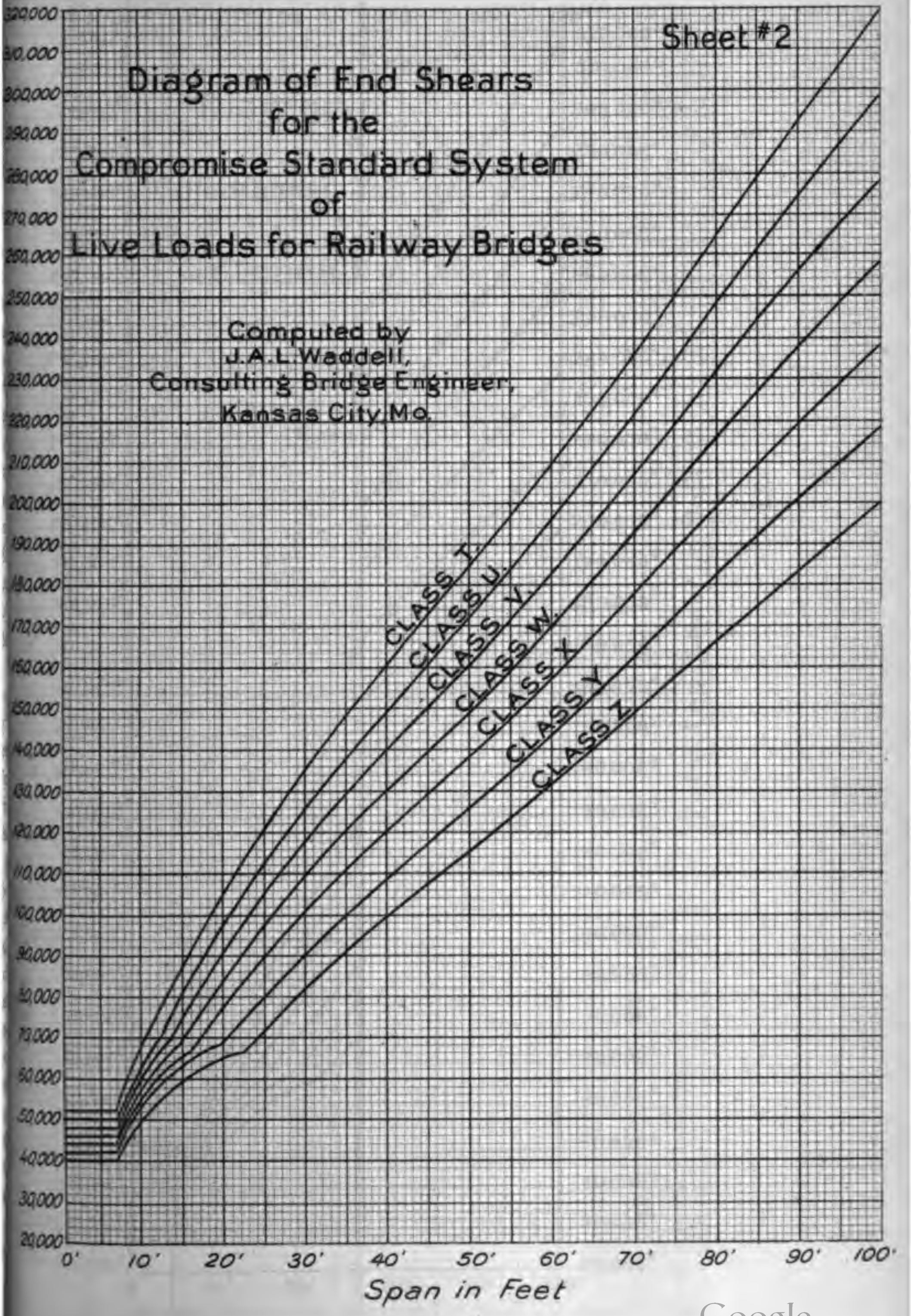
PREFACE.

The various steps taken in the preparation of this pamphlet were as follows:

About two years ago the author presented to the American Society of Civil Engineers a paper entitled, "Some Disputed Points in Railway Bridge Designing," in which he advocated the adoption of a few standard train loads for railway bridges instead of the almost innumerable ones then in use, offered a set of loads for discussion, and urged that the "Equivalent Uniform Load Method" of computing stresses be adopted instead of the burdensome method of wheel concentrations that has been in vogue for the last ten years. This paper received a very thorough discussion, from which it was evident that bridge engineers and railway engineers as a whole would be glad to settle upon a few standard loadings, and to adopt some simple equivalent method of computing stresses. Most of those who desired the abandonment of the "Concentrated Wheel Load Method" advocated the adoption of the "Equivalent Uniform Load Method," but a few favored the "Single or Double Concentration Method" with a constant car load.

This paper with the discussions was published in the February and March, 1892, number of the *Transactions* of the American Society of Civil Engineers, and was reviewed very generally by the technical press, attention being paid principally to the subject of equivalent loads. These reviews started a series of letters, principally by the author, printed at first in the *Railroad Gazette*, and later also in the *Engineering Record*, in which the subject of equivalents was thoroughly and exhaustively treated, the effect thereof being to prove that the "Equivalent Uniform Load Method" gives results which are accurate enough for all practical purposes, and that neither the "Single Concentrated Load Method" nor the "Double Concentrated Load Method" gives results coinciding at all closely with those found by the theoretically exact method of "Wheel Concentrations."

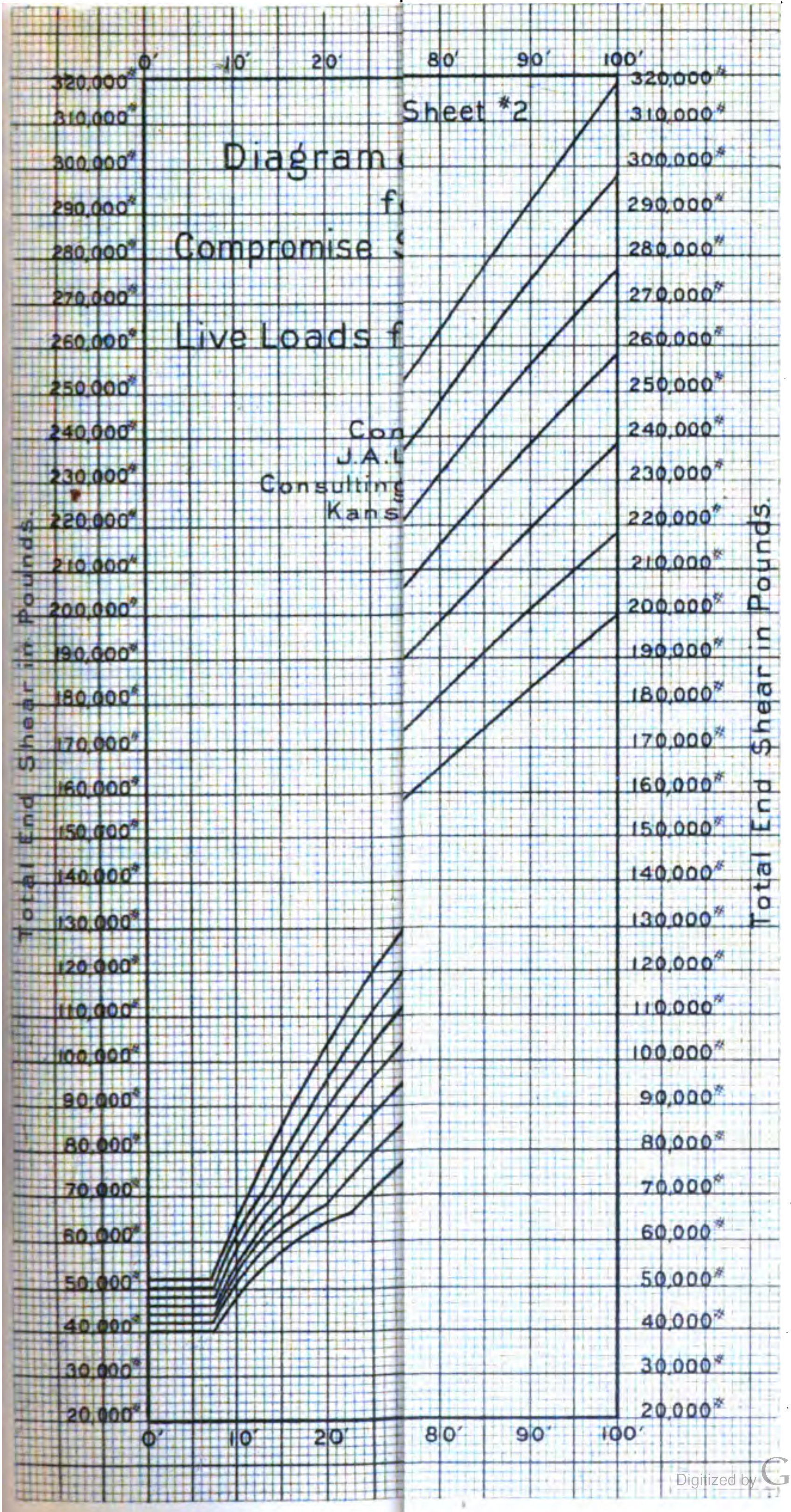
In November, 1892, the author sent a circular letter to all the chief engineers of railroads in the United States and Canada who are members (in any grade) of the American Society of Civil Engineers, and to every other member of that society connected with or specially interested in the designing, building, or operating of railroad bridges. This letter solicited a ballot on certain "Disputed Points in Railway Bridge Designing," foremost among which were those of standard live loads and a simple equivalent method of computation. The number of responses received was as great as could have been expected; and the result was that about eighty-



Sheet #2

Diagram of End Shears
for the
Compromise Standard System
of
Live Loads for Railway Bridges

Computed by
J.A.L. Waddell,
Consulting Bridge Engineer,
Kansas City, Mo.


Sheet *2
Diagram
f
Compromise
Live Loads f
Con
J.A.L
Consulting
Kans
Total End Shear in Pounds.
Total End Shear in Pounds.
0'
10'
20'
80'
90'
100'
320,000#
310,000#
300,000#
290,000#
280,000#
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two per cent. of those who voted were in favor of adopting a "Standard System of Live Loads for Railway Bridges" similar to that proposed by the author, and eighteen per cent. were opposed to same; and eighty-two per cent. of those who voted were in favor of abandoning the "Concentrated Wheel Load Method" and eighteen per cent. were in favor of retaining it. Of the former, seventy-eight per cent. favored the "Equivalent Uniform Load Method," and twenty-two per cent. were in favor of either the "Single or the Double Concentration Method." A number of gentlemen who responded made valuable suggestions in respect to the standard system of live loads propounded, and by the aid of these the author prepared a proposed "Compromise Standard System of Live Loads for Railway Bridges," and submitted the same as before for a final ballot in May, 1893.

The number of replies received showed that great interest was taken in the question; and the result of the ballot was ninety per cent. in favor and ten per cent. opposed to the proposed standard.

In accordance with the promises made in the circulars and letters before mentioned, the author herewith presents to the civil engineering profession the following curves of total end shears on plate girder spans and of equivalent uniform loads. A number of complimentary copies of this pamphlet will be distributed in the immediate future, after which it will be for sale by *Engineering News.*

J. A. L. W.
KANSAS CITY, MO.

September 1, 1893.

METHOD OF UTILIZING THE EQUIVALENT LOADS.

In calling for bids on bridge work to be accompanied by designs for the structures, a railroad engineer can nominate any bridge specifications whatsoever, standard or otherwise, and at the same time specify that the live loads are to be taken from the "Compromise Standard System," and that the "Equivalent Loads" thereof are to be employed.

In this "System" will be found from "Class Z" to "Class U," inclusive, a close approximation to any live load that an engineer is likely to want to use; and if, for a certain car load, some engineer should prefer a heavier or lighter engine loading, he can obtain practically what he wishes by specifying that one class is to be used for floor systems and primary truss members, and another class for main truss members. The author does not advise this, however, except in the case of double track bridges, where it would be advantageous to use a certain class for floor systems and primary truss members and a lighter class for the trusses, because the chances of there being two, full, maximum train loads on the span at the same time are generally very small. It might be well to carry this idea even further by specifying, for instance, "Class V" for stringers, "Class W" for floor-beams and primary truss members, and "Class X" for main truss members of double track bridges. Such a method would be in accordance with the theory of probabilities. That theory, however, would not apply to single track bridges, for which the locomotive and car loads of the "Compromise Standard System" have been properly adjusted.

The "Equivalent Uniform Load Method" reduces to a minimum the labor of making computations of stresses in bridges. The correctness of this statement will be rendered evident by the ensuing explanations of the use of the method. As for its exactness, if anyone has any doubt whatsoever about its closeness of approximation to the theoretically correct method of wheel concentrations, let him read the author's letter in the *Railroad Gazette* of July 28, 1893.* An inspection of Table I. of that communication shows that no reasonable man can object to the "Equivalent Uniform Load Method" because of its want of exactness.

In designing a bridge, one commences naturally with the stringers, then passes to the floor-beams and afterwards to the trusses, so let us follow this order.

STRINGERS.

From Plate III. find the equivalent live load per lineal foot for a span equal to the panel length, add to same the assumed weight per foot of two

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*This letter was published also in the ***Engineering Record*** of July 29, 1903, and is reprinted a few pages farther on.

stringers and the floor they support, and divide the sum by two, calling the result w; then to find the total bending moment at mid-span, substitute in the well known formula,

$$M = \frac{1}{8}\, w\, l^2$$

where l is the panel length in feet, and M the required moment in foot-pounds.

Should the total end shear be required, it can be found for each stringer by adding together the end shear given on Pl. II., the total weight of one stringer and the floor that it carries, and dividing the sum by two.

FLOOR-BEAMS.

In proportioning a floor-beam, the important thing to ascertain is the total concentration at the point where two stringers meet. The live load concentration is to be found by multiplying together the panel length and the equivalent uniform load per lineal foot given on Pl. III. *for a span equal to twice the panel length*, and dividing the product by two. It is unnecessary to describe here how the dead load concentration at each stringer support is to be found. Nor is it necessary to do more than merely mention that the live load concentration obtained for the floor-beam is the same as that required in finding total stresses in primary truss members.

TRUSSES.

These can be divided into two kinds, viz., those with equal panels and parallel chords, and those in which the panel lengths are unequal, or the chords are not parallel, or both. In the first case the stresses can be determined most expeditiously by substitution in tabulated formulæ, and in the second case by the graphical method.

CASE I.

From Pl. IV. find the equivalent uniform live load per lineal foot for the given span length and multiply same by the panel length, calling the product L. For single track bridges this must be divided by two. All the live load stresses in main truss members of single intersection bridges can be found by substituting this value of L in the table given in Carnegie's Pocket Companion (p. 211 of the 1892 edition), and in other treatises on bridges.

Just here it is proper to remark that the "Equivalent Uniform Load Method" is not applicable to trusses of multiple intersection; but that the most approved modern practice in bridge engineering does not countenance the building of trusses or girders having more than a single system of cancellation. The "Equivalent Uniform Load Method" does, however, apply to trusses with divided panels, such as the Petit truss; but as this style of truss nowadays involves almost invariably a broken top chord, its treatment herein will come under

CASE II.

Where trusses have unequal panels or chords not parallel, the first step to take is the finding of all the dead load stresses by the graphical method, starting from one end of the span and working towards the middle, where the last stress is checked by the method of moments, and the correctness of the entire graphical work is thereby proven.

The next step is to find from Pl. IV, as in Case I, the equivalent live load per lineal foot for the span, and therefrom the value of the panel-truss live load L. Next set a slide rule for the ratio of dead load per lineal foot and the equivalent live load per lineal foot for the span, and, by referring to the dead load stresses already found, read from the rule all of the live load stresses in chords and inclined end posts.

Next assume that there is an upward reaction at one end of the span equal to 10,000 pounds or 100,000 pounds, (according to the size of the bridge), due to a load placed at the first panel point from the other end of the span, then find graphically the stress in each web member from end to end of span, caused by this assumed upward reaction. Then calculate the value of the live load reaction for the maximum stress in each web member by means of the slide rule and the following formula and table in which n is the number of panels in the span, n^1 is the number of the panel point at the head of the train, counting from the loaded end of the span, and C is the co-efficient of $\frac{L}{n}$.

Live Load Reaction for head of train at $n^1 = C \times \frac{L}{n}$.

n^1	C	n^1	C	n^1	C	n^1	C
1	1	7	28	13	91	19	190
2	3	8	36	14	105	20	210
3	6	9	45	15	120	21	231
4	10	10	55	16	136	22	253
5	15	11	66	17	153	23	276
6	21	12	78	18	171	24	300

Then, still using the slide rule, find the greatest live load stress in each web member by the following equation:

$$\text{Stress required} = \text{Stress from Assumed Reaction} \times \frac{\text{Actual Reaction}}{\text{Assumed Reaction}}.$$

Where the panels are divided as in the Petit truss, and where inclined sub-posts are employed, the *tensile* stress in the *upper* half of each main diagonal thus found will have to be corrected by subtracting therefrom a stress equal to $\frac{L}{2}$ sec. A, where A is the inclination of the diagonal to the vertical. But when inclined sub-ties are used instead of inclined sub-posts, the correction just referred to will apply only to the *compressive* stresses in the *lower* halves of the main diagonals. The reason for making this correction, as will be at once evident to anyone who is accustomed to finding stresses in Petit trusses, is that the method above outlined ignores the subdivision of the panels when ascertaining by graphics the stresses caused by the assumed upward reaction.

Extracts from *The Engineering Record* of June 3, 1893.

RAILROAD STANDARD MOVING LOADS.

The result of Mr. J. A. L. Waddell's solicited ballot on standard moving loads is given in full in the circular letter below, and comments will be found on the editorial page of this issue of *The Engineering Record.*

Dear Sir: On November 19 of last year I sent you a circular letter in respect to "Certain Disputed Points in Railway Bridge Designing," enclosing a ballot with the request that you fill it out and return it to me. I now write you to report the result of the ballot, and fearing that you may have forgotten the purport of the questions raised, I reproduce in this letter the various items in the order in which they appeared on the ballot sheet.

Ballots were sent to 253 engineers, some of whom replied immediately. After waiting about six weeks, I sent a personal letter to each engineer who had not replied, with the result that I have obtained up to date answers from all but 93, making the percentage heard from 63, and that not heard from 37. This is a pretty fair showing, considering that engineers as a class are very busy men, that many of them spend a great deal of their time in the field, which makes letter writing burdensome, and that many of the gentlemen I addressed, especially the railroad engineers, had probably not read my paper on "Some Disputed Points in Railway Bridge Designing," to which the circular had reference. Again, I feel sure that a number of the circulars failed to reach the parties to whom they were sent, through either faulty addresses or misplacement. I am led to believe this from the replies to the personal letters that I sent as reminders. On the whole, I am well satisfied with the result of the ballot, and here beg to thank the gentlemen I addressed for the courtesy they have shown me, and for the interest they have taken in the subject.

Of the 160 gentlemen heard from, 20 pleaded illness or lack of time to spare for the work necessary to investigate the subject sufficiently to send intelligent replies, 11 excused themselves as not being posted on the points raised, 18 were opposed to balloting on such matters, and 111 sent in ballots.

Of those who failed to answer, 54 per cent. are railroad engineers, 43 per cent. bridge engineers and 3 per cent. engineers in other branches. Of those pleading illness or lack of time, 65 per cent. are railroad engineers and 35 per cent. bridge engineers. Of those claiming to be not posted, 82 per cent. are railroad engineers and 18 per cent. bridge engineers. Of those opposed to balloting, 39 per cent. are railroad engineers and 61 per cent. bridge engineers. And of those who sent in ballots, 42 per cent. are railroad engineers, 47 per cent. bridge engineers, and 11 per cent. engineers in other branches, principally that of civil engineering instruction.

I give you these percentages in order that you may know what branches of the profession are represented in the ballots.

The following is the result of the ballot:

Item No. 1.—19 in favor of adhering to the concentrated wheel load method of computing stresses, which is now in vogue; 16 in favor of adopting a constant car load per lineal foot, headed by a single locomotive excess load; 3 in favor of the latter, except that they specify two locomotive excess loads; 69 in favor of adopting the method of "equivalent uniform loads," advocated by Mr. Waddell, in his paper on "Some Disputed Points in Railway Bridge Designing."

Item No. 2.—75 in favor, 16 not in favor of adopting a system of train loads similar to that proposed by Mr. Waddell, on pages 89 and 90 and Plate XVI., of the *Transactions* of the American Society of Civil Engineers, Vol. XXVI., modified by the addition of certain heavy concentrations for short spans, as indicated on page 272 of the same volume; 32 in favor, 32 not in favor of increasing the wheel loads for tenders, given on Plate XVI.; 15 in favor, 41 not in favor of increasing the lengths of engines as their weights are increased; 16 in favor, 45 not in favor of increasing the loads on the engine axles, given on Plate XVI.; 10 in favor, 57 not in favor of the addition of train loads for mountain lines in which the engine loads shall be heavy and the car loads light; 14 in favor, 55 not in favor of abandoning the loads proposed by Mr. Waddell and substituting therefor others.

Item No. 3.—108 in favor, none not in favor of having made, at the expense of either private parties or the U. S. Government, an exhaustive set of experiments to ascertain the dynamic effects of live loads applied at various speeds on bridge members of all kinds.

Item No. 4.—106 in favor, 2 not in favor of having made, at the expense of either private parties or the U. S. Government, an elaborate series of tests of full size members of steel bridges, especially compression members of all kinds.

Item No. 5.—98 in favor, 6 not in favor of the *ultimate* adoption by the profession of standard specifications for bridge designing, which shall specify clearly and concisely, in every particular, such important matters as loads, intensities of working stresses, quality of materials, workmanship, etc., but at the same time shall not infringe upon the individuality of the designer.

* * *

(Signed) J. A. L. WADDELL.

EDITORIAL.

STANDARD MOVING LOADS FOR RAILWAY BRIDGES.

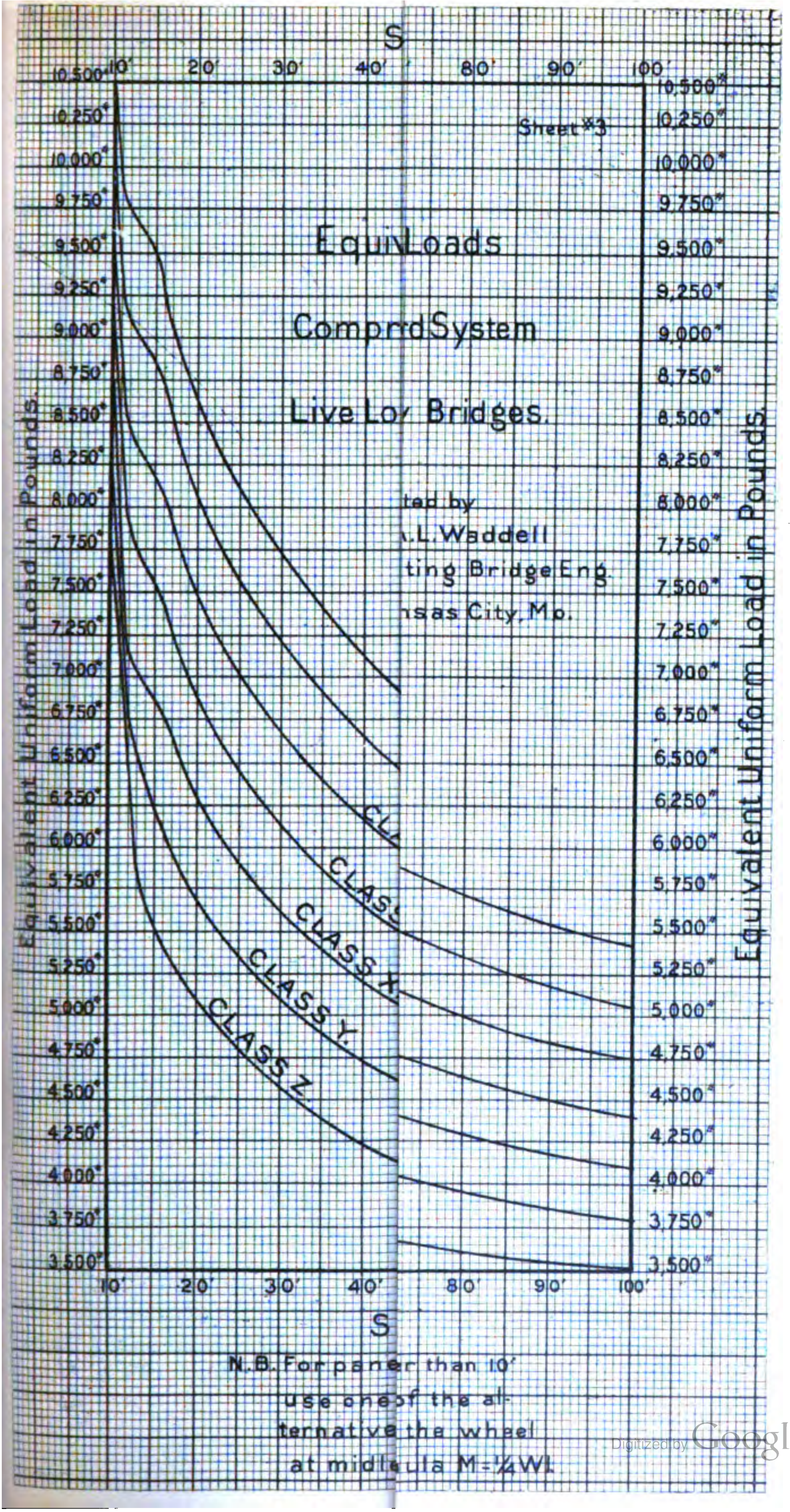
The paper on "Certain Disputed Points in Railway Bridge Design," by J. A. L. Waddell, M. Am. Soc. C. E., has attracted considerable attention in consequence largely of its proposition to substitute standard moving loads for the almost infinite variety now given in various bridge specifications. "The Engineering Record" has already expressed favorable views in regard to the standardizing of not only railway moving loads, but also the specifications governing the designs of railway bridges. There are strong reasons for believing that increased excellence both of design and of material would be secured by a reasonable uniformity of specifications, and it is an absolute certainty that great saving of labor to the builders of bridges would be attained. It is, however, probably far too much to expect that individual preferences, which engineers in common with other men possess, will ever be displaced by systematic requirements for structural design.

It would seem to be a much more hopeful task to undertake to secure certain sets of standard moving loads within whose range the needs of practically every railroad in the country will be found. The prospective use of such standard loads would probably not trench upon the sensitiveness of any individual in regard to the limiting of the exercise of his special preferences; the latter could be still exercised upon the various features of any particular design. This view seems to be strengthened by the result of the balloting which Mr. Waddell solicited last November. Without going into the details of the returns, which will be found in another column, the results appear to indicate that the preponderating desire among those who have to do with railroad moving loads is in the direction of standardizing them; and not only that, but it would also appear that the

same engineers are in favor of substituting in their bridge computations what is loosely termed "equivalent uniform loads" for the axle concentrations. The advantages of standard loads are so evident that we are not surprised to learn the large ballot in their favor, nor indeed are we surprised that there should be such a strong ballot in favor of the so-called "equivalent uniform loads." The meaning of the former proposition is apparent on the surface of its statement, and its advantages are equally clear, while the latter has a pleasing sound since it involves the displacement of the cumbersome concentration system by a simple uniform load, and thus seemingly leaves little or nothing now to be desired. The uniform load must be supplemented for short spans by certain arbitrary concentrations, but as the latter belong to short spans only, which will almost or quite invariably be built as plate girders the complication is not deemed an important feature of the system. The main point is the "uniformity" and the "equivalents."

We have before expressed ourselves as of the opinion that the equivalent uniform loads do not fill the complete requirements of the case, and continued reflection and examination of the question confirm us in this opinion. We are further of the opinion that if a great majority of the engineers who voted for it appreciated just what it means, the uniform train load with a single concentration either at its head or at any point would have been preferred. It gives us much pleasure to observe that the weight of engineering opinion is in favor of abolishing the crude, deceptive, and awkward concentrations, and if those most interested should choose to adopt an incomplete remedy for the difficulty, we shall consider even that advantage of the greatest possible value. It only seems the more a pity not to bring the movement for improvement to its full fruition at once, for we do not believe that the uniform equivalent loads will, for any great length of time, be considered satisfactory. It is irrational, and although the resulting errors involved are too small to be of any practical conseqence, we think there would be an essential gain, at least of a professional character, in adopting a system of loading that would be perfectly elastic, perfectly simple, and involving no crudities in the actual computations.

Calculations for bridge design should be made on a basis either of a uniform train of locomotives or else a loaded train of cars of the proper intensity with the two coupled locomotives, either in the front or rear or at any intermediate point. The equivalent uniform load plan does not provide for this condition of loading, and although it can be so extended as to include that requirement, the end can only be accomplished by further "equivalents" and possibly increased eccentricities of the method. A uniform load with a single concentration at its head or at any point can be made to cover every possible supposition of loading or length of span without any juggling with an equivalent device and with approximations at least as close to the ideal concentration stresses as those of the equivalent uniform loads and possibly more so. If the equivalent uniform loads are all that the engineering practice of the present time will stand, let us by all means have them, leaving for future efforts further improvements which are certainly bound to come, but it would be far better to introduce at once a simple system of loading which would meet the complete requirements of the case for all time to come.



Sheet #3

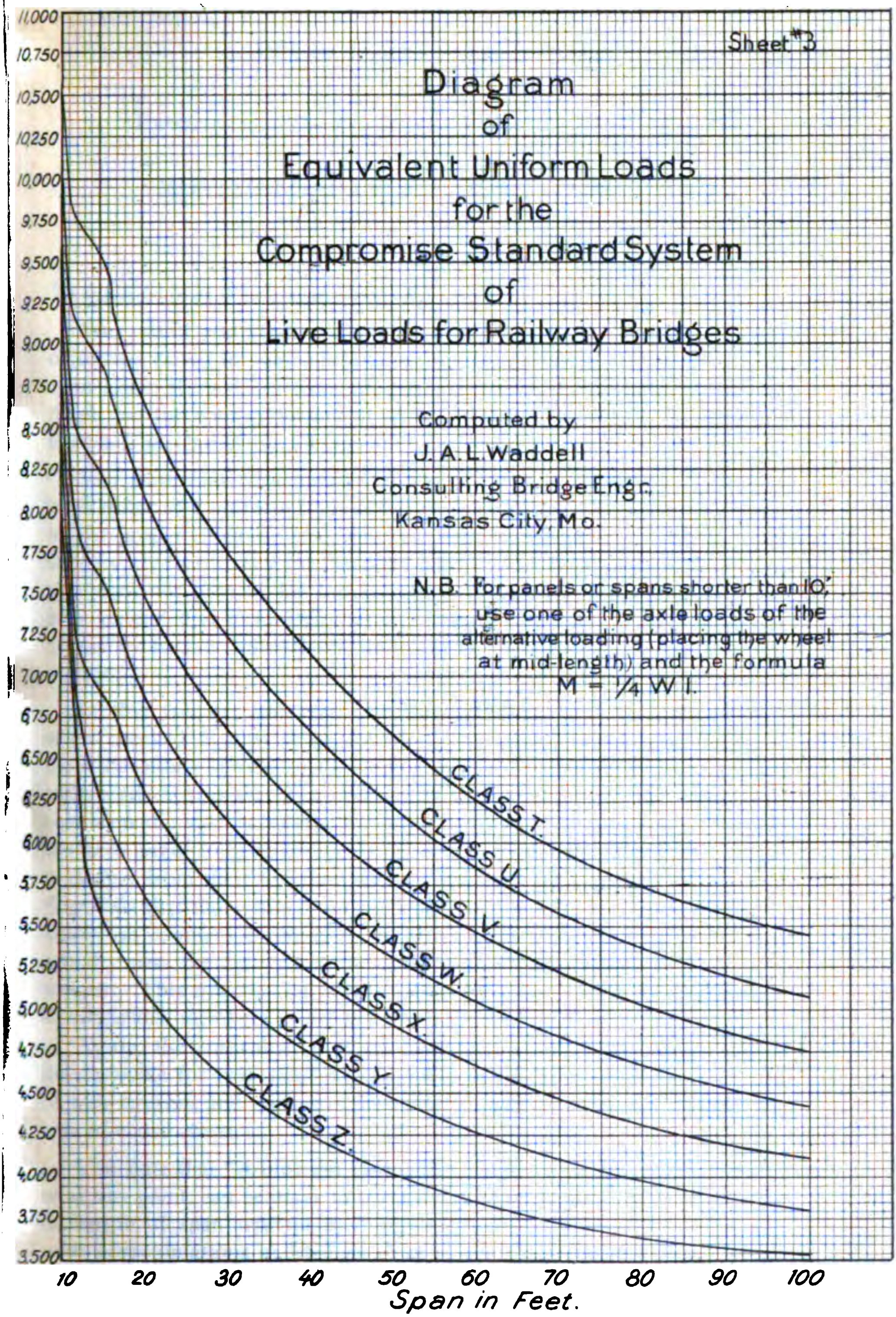
Equiv Loads

Comprrd System

Live Lo/ Bridges.

ted by
A.L. Waddell
ting Bridge Eng.
nsas City, Mo.

N.B. For paner than 10'
use oneof the al-
ternative the wheel
at midleula M=¼WL



Sheet #3

Diagram
of
Equivalent Uniform Loads
for the
Compromise Standard System
of
Live Loads for Railway Bridges

Computed by
J. A. L. Waddell
Consulting Bridge Engr.
Kansas City, Mo.

N.B. For panels or spans shorter than 10', use one of the axle loads of the alternative loading (placing the wheel at mid-length) and the formula M = 1/4 W l.

Extracts from *The Engineering Record* of July 8, 1893:

MOVING LOADS FOR RAILWAY BRIDGES.

KANSAS CITY, MO., June 12, 1893.

To the Editor of The Engineering Record.

SIR: Will you kindly permit me to reply in your columns to certain objections raised in your editorial of June 3 against the "Equivalent Uniform Load Method" of computing stresses in bridges? But first let me thank you for your endorsement of my effort to establish a few standard live loads instead of the almost innumerable loads at present in use.

You state that "Calculations for bridge design should be made on a basis either of a uniform train of locomotives or else a loaded train of cars of the proper intensity with the two coupled locomotives, either in the front or rear or at any intermediate point. The equivalent uniform load plan does not provide for this condition of loading, and although it can be so extended as to include that requirement, the end can only be accomplished by further 'equivalents' and possibly increased eccentricities of the method."

In this you are mistaken, for the equivalent uniform load stresses, when checked against those found by the actual wheel concentrations, show variations of very small amount indeed for all main diagonals, posts and chords of trusses. For counters of short spans there are rather large errors on the side of safety; but these are really an advantage, for such counters ought to have an excess of section, especially as it is the practice to deduct from their live load stresses the dead load stresses of the main diagonals that they cross. As the length of the span increases, the safety errors on counters continue to decrease, until for very long spans they actually pass the zero point and show a small percentage on the side of danger. This question of counter-stresses is fast losing its importance, as adjustable members in bridges are being less used every year.

Again, the equivalent uniform load method, as I am advocating it, does provide for two coupled locomotives at the head of the train in case of web stresses, and with cars preceding as well as following them in the case of chord stresses.

You state that "A uniform load with a single concentration at its head, or at any point, can be made to cover every possible supposition of loading or length of span without any juggling with an equivalent device and with approximations at least as close to the ideal concentration stresses as those of the equivalent uniform loads, and possibly more so." Now, I have investigated this question quite thoroughly and cannot find any such result for the single concentration method. In fact, I find, as stated some months ago in the *Railroad Gazette,* that both the danger and safety errors for the single concentration system are fully twice as great as those for the equivalent uniform load system, in comparison with the so-called exact method of wheel concentrations. I do not think it possible to establish a uniform load with either single or double concentrations that would be practically equivalent to a load consisting of two locomotives followed by a uniform load of cars. In one case that I investigated exhaustively I found that the danger errors ran as high as 5 per cent., as did also the safety errors. I find it to be impracticable to adjust the concentrations so as to be satisfactory for both floor system and trusses, or for both short and long plate-girder spans; while the equivalent load method *gives practically exact results* for floor systems and all plate-girder spans, and very close agreements for all truss spans, the longer the span the closer being the agreement.

I grant that all this does not prove the single concentration system to be a bad one; and that if adopted it would cause serious errors in calculations. In my opinion it is infinitely preferable to the heart-breaking method of wheel concentrations. But here is a point that you appear to overlook—*the single concentration method requires just twice as much figuring as does the equivalent uniform load method.* This ought to be evident when one remembers that we have in the former to find, first, the stresses for the uniform car load, then those for the concentrations and add the results together, while in the latter we have to find the stresses for merely a uniform load given by a diagram.

I have already computed all the equivalents for the proposed "Compromise Standard System of Live Loads," although the ballot is not yet closed. It is probable that I am safe in so doing, as thus far for one vote opposed there are seven or eight votes in favor of the system. The results of my computations are eminently satisfactory, showing as they do that the equivalent load method gives stresses identical with those given by the wheel concentration method for all floor systems and primary truss members of all spans, and for all plate-girder spans; and results practically identical for main truss members of all spans exceeding, say, 150 feet in length. For truss spans below 150 feet the errors are appreciable but by no means excessive (not more than half as great as they would be by either the single or the double concentration method). Moreover, for these short spans the equivalent loads have been adjusted so as to make most of the errors on the side of safety, while for spans of 150 feet and over the average for all main web and chord members has been taken, as nearly as may be. Nor has there been any "juggling" in finding these equivalents.

General managers of railroads, and even some chief engineers, when asked to adopt a single uniform load headed by a single concentration as a standard live load for their bridges, are very liable to reply about as follows:

> "Our standard consists of two engines each weighing —— pounds distributed thus, followed by a train of cars weighing ——— pounds per lineal foot. Now I cannot see much similarity between your proposed load and ours; and it can be shown that no single concentration or no two concentrations in the neighborhood of 50 feet apart combined with our uniform car load will give results agreeing at all closely for all spans and panels with those found by our standard." You reply, "What matters this if the single concentration and uniform car load be assumed as a standard and used as such?" I answer, that such a loading does not satisfy me, because I desire as a standard a loading that will correspond as nearly as practicable with the greatest loads produced by our trains, plus, of course, a reasonable allowance for contingencies and future increase in weight of rolling stock. Such a standard is the one we have been using; but I am willing to change it slightly, if necessary, in order to use one or more of the loads of any system adopted as a standard by the engineering profession, for the purpose of simplifying bridge designing. Again, as most bridge engineers claim that the concentrated wheel load system is extremely laborious, that it involves entirely unnecessary refinement in figuring, that for any live load consisting of engines followed by cars a curve can be constructed which will give at a glance the equivalent uniform load for any span or panel, thus reducing greatly the labor of making computations, and that the variations by this method from the results given by the concentrated wheel load method are quite small, I am willing to specify that such a curve shall be used instead of the diagram of engine and car loads.

You say in your editorial, "The uniform load must be supplemented for short spans by certain arbitrary concentrations, but as the latter belong to short spans only, which will almost or quite invariably be built as plate girders the complication is not deemed an important feature of the system. The main point is the 'uniformity' and the 'equivalents.'"

In reply to this I would state that the equivalent loads on my new diagrams apply to all spans from 10 feet upward, and that the curves thereon were computed for both the consolidation engines and the special, heavy axle loads. If any one desires to use a span or panel less than 10 feet long, it will simply be necessary for him to find the bending moment by the formula $M = \frac{1}{4} W l$, where W is the weight on one axle for the alternate heavy loading for very short spans, and l is the length of span. But it is very seldom indeed that any one will want to use a span or panel length as short as 10 feet. I cannot remember just now any such case in my practice. The necessity for using this formula for spans shorter than 10 feet will be indicated clearly on the diagram.

Finally, I would state that I do not see why you believe that the equivalent uniform load method does "not fill the complete requirements of the case" and why you call the method "irrational." I have shown repeatedly that it gives results agreeing for all cases with those found by the so-called exact method as closely as the most exacting practical man can require. As for the method being irrational, is it any more so than the single concentration method, which in the first place calls for an absolutely impossible loading, and in the second place involves (in common with the equivalent uniform load method) an assumption that is theoretically incorrect —viz., that the loading is all concentrated at panel points, and that the panel point just ahead of the train receives no load whatsoever?

If you will withhold your final judgment upon this matter of the equivalent uniform load method until you receive my next circular, which will contain my new diagrams of end shears and equivalent uniform loads, you may perhaps be inclined to look upon the method with more favor. It is my intention to publish later, in tabulated form, the results of the calculations made in determining the equivalents for the proposed "Compromise System of Live Loads for Railway Bridges," and to show the variations from exactness involved by their use for spans up to 500 feet in length.

I thank you in advance for your courtesy in publishing this letter.

J. A. L. WADDELL.

EDITORIAL.

MOVING LOADS FOR RAILWAY BRIDGES.

We print in another column of the present issue of "The Engineering Record" the comments of Mr. J. A. L. Waddell on our editorial of June 3d. We do not think that the subject warrants a treatment extended much beyond its present limits, but before closing our editorial opinions we shall make correction or answer to two or three points raised in Mr. Waddell's letter, and give expression to views which were omitted in our issue of June 3d. Although it is extremely desirable that simplicity and uniformity should be introduced into this division of railway bridge design, we apprehend that it is like a great many other simple and uniform things which are much to be desired, but which unfortunately are seldom or never realized, and we doubt very much whether further discussion will either develop new features of the subject, or accomplish much in securing the desired end.

In the first three paragraphs of his letter, Mr. Waddell makes much of the fact that his proposed equivalent uniform loads produce stresses which are but a few per cent. different from those caused by the actual engine concentrations and uniform train load. As nobody denies that point, we cannot see that any useful purpose is subserved by its constant reiteration. Indeed, it is a matter of very little consequence whether any assumed load gives results 2 or 5 per cent. more or less, or even 10 per cent. more than those caused by the concentrated load system, when it is borne in mind that the ordinary track irregularities and incidents of the motion of a locomotive may produce variations represented by at least double the greatest of those percentages. If any system of assumed loading has no more to commend it than useless refinement it is not worthy of consideration, nor do we purpose to give any further attention to that point.

We infer from the present communication that Mr. Waddell has changed his proposed "equivalent uniform loads" in some rather material features from those given in his original paper, nor are we able to infer just what those changes are. We made the important point in our previous comment that any proper system of computation ought to provide either for a train of locomotives or for a pair of locomotives at any point in the train, and he states that his present proposed equivalent uniform loads provide for those conditions. Inasmuch as his original paper does not make any such provision, it is a matter of some interest to learn just how this is accomplished. We also infer from his present communication that the extra loads for end shears for short spans, which were prescribed in his original paper, are now discarded in favor of a new system of equivalent uniform loads, inasmuch as he says that "the equivalent loads on my new diagrams belong to all spans from ten feet upward." This is a distinct gain, and, although we did not in our former comment consider the old arrangement an essential disadvantage to the system, it shows that further investigation of the original proposition has led Mr. Waddell to modify his position in at least that respect. That change of view prompts us to express an apprehension that a further consideration, or use, might suggest further changes in some features of the proposed load arrangements, and, if that is the case, a material portion of the supposed advantages will be, of course, purely imaginary.

One passage in his communication shows that he fails to comprehend one of the main points which we make in reference to the uniform load with a single or double concentration at any point in it. He states that the danger and safety errors for the single concentration system are fully twice as great as for the equivalent uniform load system. Now, as a matter of fact, if the single or double concentrations are so taken as to represent the total locomotive excess over the uniform train load of the same length as that of the two locomotives, there can be no danger error; the entire error is sure to be on the side of safety, and whether it is 2, 3, or 6 or 7 per cent. is a matter of no real consequence, for the reasons which we have already stated. There is, however, another consideration bearing upon the single or double concentration method which is of far more weight than a matter of 2 or 3 per cent. variation from the standard stresses. We do not believe that the engineering officials or managers of the railroads of the country will permit themselves to be bound to any rigid system of prescribed loads, however ready the engineers interested may be to cast a ballot for it. It is not a characteristic of human nature to act along such smooth and well-defined lines. It would be most desirable to have a few fixed systems of loading, and we earnestly wish that result might be brought about, but we do not believe that it is feasible, or that railroad companies

can be brought to the adoption of such rules for their bridge computation. We think, therefore, that it would be much better in every way to attempt to secure not absolute uniformity of loads, but uniformity of simple methods of computation which will leave every railroad or bridge engineer free to accommodate himself to the infinitely varied local circumstances under which he may from time to time be obliged to act. We do not believe that he can be induced to abandon individual features of loading to which he has been accustomed, or for which he may for his own reasons have special preference, but we do think it quite feasible to induce him to permit those loads to be subjected to a uniform and simple method of treatment in the necessary computations for his bridge design; and, if there is any other way or any better way than the uniform train load headed by or containing one or two concentrations which represent the locomotive excesses, we have not heard of it, but shall be very glad to endorse it if some one will bring it to public notice.

It is a fundamental error to state that such a system of loading necessitates just twice the labor of computation required by the equivalent uniform load, and we are surprised that Mr. Waddell should have fallen into such an error of statement, although double the labor involved in the computation for a uniform load is too small a matter in connection with this question to be of any importance. We maintain that the equivalent uniform load method fails to fill the complete requirements of the case, for the reasons we have already stated in considerable detail, and it is irrational, because under its assumed character it does not give the results implied by its name and its treatment.

Extract from *The Engineering Record* of July 29, 1893.

STANDARD LIVE LOADS FOR RAILWAY BRIDGES.

To the Editor of The Engineering Record.

SIR: In accordance with a promise made a short time ago in one of my communications on the subject of "Standard Live Loads for Railway Bridges," I herewith present to the engineering profession the results of the calculations made in computing the equivalent uniform loads for the proposed "compromise standard," together with certain deductions obtained therefrom by means of some auxiliary computations. All of the calculations referred to were made by my assistant, Mr. Ira G. Hedrick, and were checked by other computers. The computations for determining the curves of the equivalent uniform loads received an additional check by the plotting, because the curves are so regular that an error as small as five pounds per lineal foot could be readily detected by the eye; and, in fact, several small errors were thus found before the check by independent figuring was made. These curves, and those for total end shears on plate-girder spans, are soon to be published for distribution, and I hope that you will see fit to reproduce them in full size in your paper.

On account of an editorial statement in *The Engineering Record* to the effect that a constant car load per lineal foot combined with a single concentrated load, properly determined, will produce stresses agreeing as closely with those found by the so-called exact method of wheel concentrations as do stresses found by the equivalent uniform load method, Mr. Hedrick, at my suggestion, continued his calculations so as to settle conclusively the correctness or incorrectness of this claim. Because of our having on hand the calculations for the equivalent uniform loads, we were well equipped for making the necessary investigations without the expenditure of an undue amount of labor. In dealing with the single and double concentrated load methods, we have endeavored to be perfectly fair; and have done our best in determining the values of the concentrations to obtain results agreeing as closely as possible with the theoretically correct ones. Should anyone think that he can make a better showing for the single or double concentrated load method than we have done, the results of our calculations of stresses by wheel concentrations will be placed at his disposal; and he can rely on their correctness, for they have been most thoroughly checked. However, I shall make some deductions presently which will nullify the effect of any unfavorable determination of the values of the concentrations, and eliminate entirely what may be termed the "personal equation" in our computations.

Our curves were prepared as follows: For truss spans the shear and moment for every panel of the 100-foot, 150-foot, 200-foot, 250-foot, 300-foot, 400-foot and 500-foot spans were computed by the concentrated wheel load method for both Classes "Z" and "U" (the extremes), and the equivalent uniform loads were determined therefrom for each diagonal and chord section, after which the average of these for each span was taken for plotting the curves, except in the case of the 100-foot spans, where the equivalent uniform loads were made a little greater than the average. After plotting the curves for Classes "Z" and "U," those for the intermediate classes were interpolated very accurately by determining the end shears. It was found, as was anticipated, that a direct average interpolation gave correct results.

Next the curves for equivalent uniform loads and total end shears for plate girder spans of all classes were computed by the exact method and plotted.

We next took up the consideration of the single concentration method, confining our attention entirely to the extreme classes—viz., "Class Z" and "Class U," although, by the way, a "Class T" has since been added (for floor systems and primary truss members only), in order to include the loadings of one or two railway companies which are greatly anticipating future increase in weights of rolling stock.

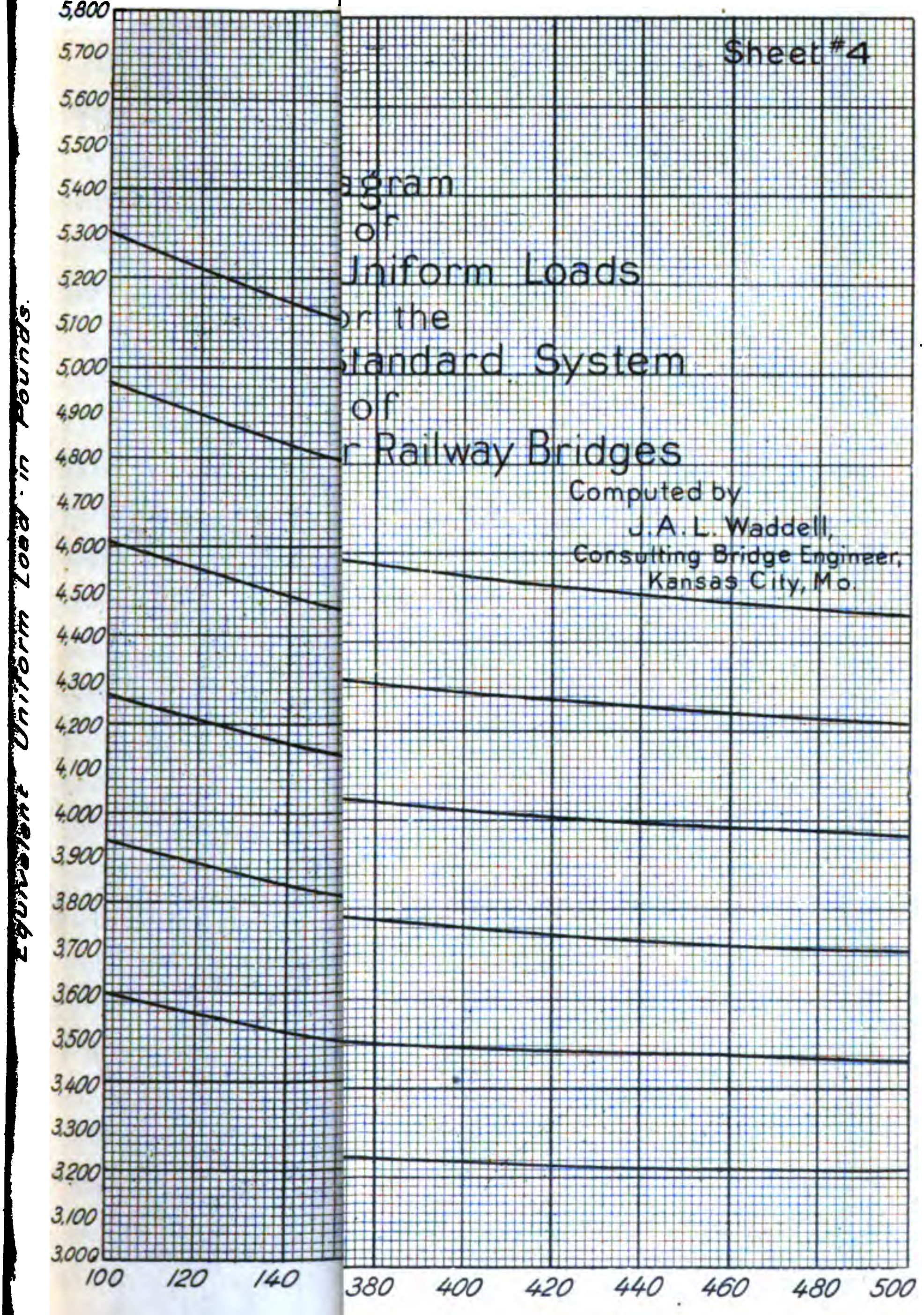
The first step was to find for each main diagonal, and each chord section of the 150-foot, 300-foot and 500-foot spans the single concentrated excess load, which, in addition to the uniform car load, would produce the same shear or moment as that found previously by the wheel concentration method. These excesses for each span were then averaged, and, finally, the average of these averages was taken as the most nearly correct excess load for main truss members. The results were respectively for Classes "Z" and "U," 39,372 pounds and 88,368 pounds.

Next the average single concentrations for all plate-girder spans between 20 feet and 100 feet for Classes "Z" and "U" were determined and found to be respectively 24,577 pounds and 51,750 pounds. Considering that the floor system is fully as important as the trusses, we thought it proper to average these last concentrations with those found for main truss members in order to determine the final single concentration for each class, making the final concentrations respectively for Classes "Z" and "U" 32,000 pounds and 70,000 pounds.

Applying these to both floor systems and trusses, we found the errors so great that it proved conclusively that *no single concentration can be assumed which combined with the constant car load will give results that even approximate to those found by the concentrated wheel load method.* For instance, in Class "Z" the greatest floor system error was 21.6 per cent. on the side of safety, and in the trusses of the 150-foot span the errors on main diagonals and chords varied from 8.1 per cent. safety to 3.1 per cent. danger, while for the 100-foot span the showing would have been even worse. For Class "U" the errors for floor system ran as high as 36 per cent., and those for main members of the 150-foot span varied from 7.3 per cent. safety to 4.3 per cent. danger.

Clearly, there was nothing to be done except to adopt one concentration for the floor system and primary truss members and another for the main truss members. After considerable deliberation we decided upon the following concentrations:

	For Floor Systems, etc.	*For Main Truss Members.*
Class Z	25 000 pounds	40 000 pounds
" Y	30 000 "	50 000 "
" X	35 000 "	60 000 "
" W	40 000 "	70 000 "
" V	45 000 "	80 000 "
" U	50 000 "	90 000 "



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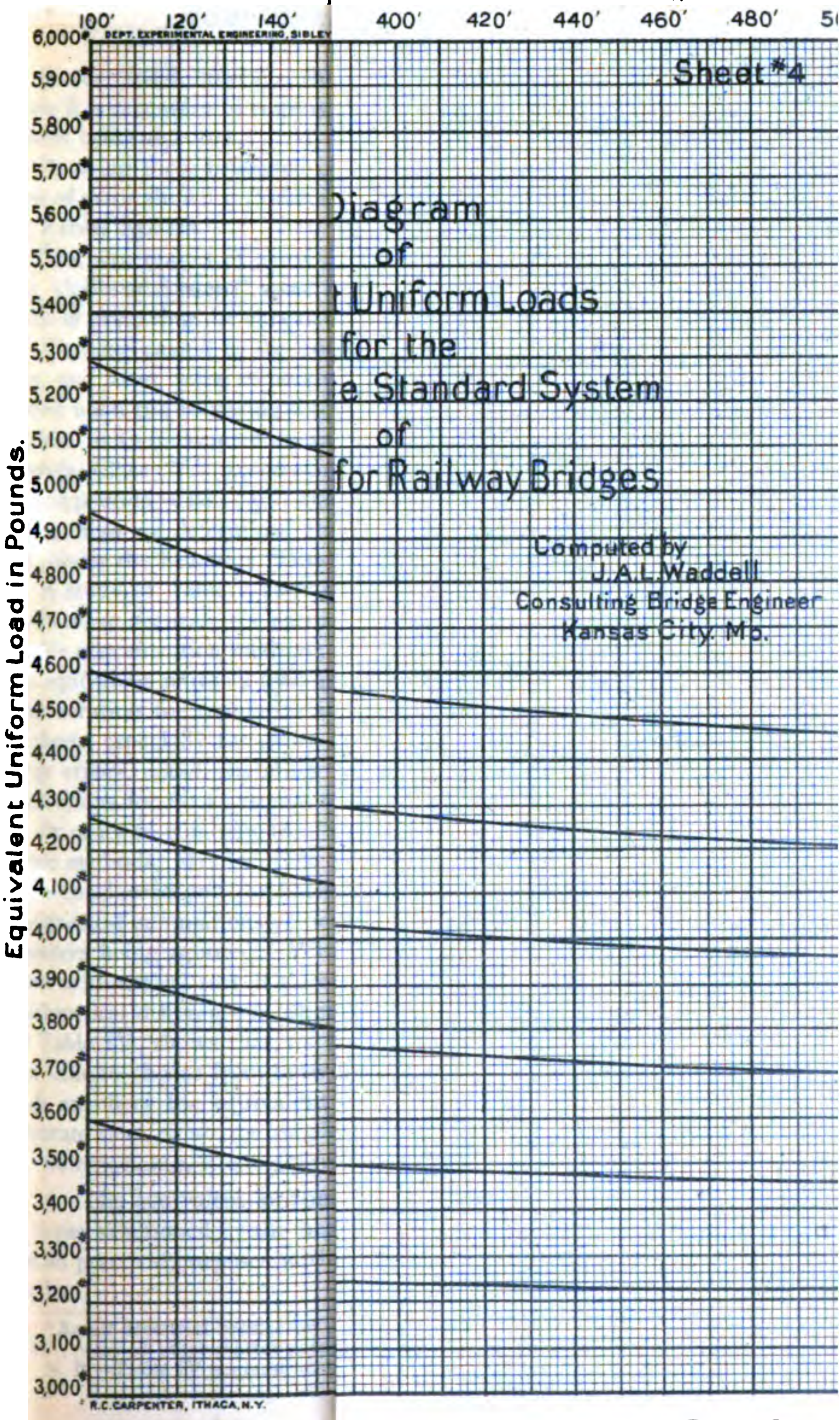
Computed by
J. A. L. Waddell,
Consulting Bridge Engineer,
Kansas City, Mo.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Equivalent Uniform Load in Pounds.
Sheet #4
Diagram
of
t Uniform Loads
for the
e Standard System
of
for Railway Bridges
Computed by
J.A.L. Waddell
Consulting Bridge Engineer
Kansas City, Mo.
R.C. CARPENTER, ITHACA, N.Y.

It was found, however, that in computing end shears for plate-girder spans it is necessary to employ the truss concentrations instead of the floor system concentrations.

By using these tabulated concentrations there were found the percentages of error shown in Tables I., II. and III. in the columns headed "Single Excess System."

The percentages of error in these tables under the headings "Equivalent Uniform System" were determined by reference to the calculations made in preparing the curves of equivalent uniform loads.

We next passed to the consideration of the double concentration system, and after some extensive calculations and due deliberation, determined upon the following excesses as being the best to use, placing them 50 feet, or two assumed average panel lengths, apart: Class "Z," 25,000 pounds; Class "Y," 30,000 pounds; Class "X," 35,000 pounds; Class "W," 40,000 pounds; Class "V," 45,000 pounds; Class "U," 50,000 pounds. By using these we determined the percentages of error in Tables I., II. and III. under the headings "Double Excess System."

A study of Table I. shows that the equivalent uniform load method is much more accurate for main truss members than either the single or the double concentration method; and referring to Table II. we see that while the equivalent uniform load gives exact results (or as nearly so as a due consideration for regularity in the curves will permit), both of the other methods, especially for short spans and stringers of ordinary length, give large errors, notwithstanding the fact that we have adopted different concentrations for floor systems and trusses.

In order to eliminate the "personal equation" entirely in comparing the three methods, Mr. Hedrick has prepared Table IV.* in which for each span considered and for both Class "Z" and Class "U," he has collected the greatest summations of percentages of error for both chords and webs, counters being ignored. When the extreme errors are of opposite kinds their arithmetical sum is taken, but when they are of the same kind their arithmetical difference is taken in determining the "summation." A study of Table IV. shows that, as far as chord stresses are concerned, there is but little to choose from between the three methods, but that in respect to web members the equivalent uniform load method is very much more accurate than either the single excess or the double excess method.

Summarizing, it is evident that we have proved the following:

1. The equivalent uniform load method gives stresses, for all bridges of types sanctioned by the best modern practice, agreeing sufficiently well for all practical purposes with those found by the concentrated wheel load method.

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*As all essential results of Mr. Waddell's compilations are given in Tables I.-III., press of other matter compels us to omit Table IV. [Ed. of Eng. Record.]
N. B.—Table IV is given on page 486 of this book. J. L. H.

TABLE I.

Table Showing Percentages of Error in Stresses Found by Equivalent Uniform, Single Excess, and Double Excess Methods of Loading.

Span Length.	Chord Members.	Web Members.	Class Z. Equivalent Uniform System.	Class Z. Single Excess System.	Class Z. Double Excess System.	Class U. Equivalent Uniform System.	Class U. Single Excess System.	Class U. Double Excess System.
100 Ft.		Batter Brace.	0.9 Danger.	4.6 Safety.	0.9 Safety.	1.8 Danger.	7.5 Safety.	1.2 Danger.
		1st M. Diagonal.	6.1 Safety.	20.2 "	8.5 "	4.5 Safety.	26.0 "	5.3 Safety.
		1st Counter.	19.9 "	60.0 "	39.0 "	13.5 "	66.0 "	39.0 "
	1st Top Chord.		3.7 "	9.6 "	0.9 "	4.9 "	15.0 "	0.8 Danger.
	Bottom "		0.9 Danger.	4.6 "	0.9 "	1.8 Danger.	7.5 "	1.2 "
150 Ft.		Batter Brace.	1.6 "	0.1 Danger.	0.1 Danger.	1.1 "	0.9 "	1.7 "
		1st M. Diagonal.	0.3 "	4.3 Safety.	3.1 Safety.	0.6 "	6.0 "	1.3 Safety.
		2d "	3.2 Safety.	12.6 "	9.0 "	1.4 Safety.	15.3 "	6.0 "
		1st Counter.	10.2 "	30.1 "	17.0 "	7.2 "	35.0 "	12.8 "
	1st Top Chord.		1.1 "	2.8 "	1.7 "	0.6 "	2.5 "	1.4 Danger.
	2d " "		1.3 "	2.6 "	0.3 "	2.6 "	4.7 "	1.6 "
	Bottom "		1.6 Danger.	0.1 Danger.	0.1 "	1.1 Danger.	0.9 "	1.7 "
200 Ft.		Batter Brace.	1.1 "	1.1 "	0.3 Danger.	0.2 "	0.8 Danger.	1.7 "
		1st M. Diagonal.	1.0 "	0.7 Safety.	1.2 Safety.	0.7 "	1.3 Safety.	0.3 "
		2d "	0.5 "	3.4 "	3.4 "	2.8 "	2.6 "	0.1 "
		3d "	0.8 Safety.	7.8 "	6.7 "	1.3 "	8.9 "	4.1 Safety.
		1st Counter.	5.9 "	18.7 "	14.6 "	2.6 Safety.	20.7 "	11.0 "
		2d "	11.8 "	35.5 "	22.2 "	7.5 "	40.3 "	17.0 "
	1st Top Chord.		0.4 "	0.4 "	0.9 "	0.7 "	0.1 "	1.3 Danger.
	2d " "		0.7 "	0.7 "	0.7 "	1.6 "	1.1 "	1.0 "
	3d " "		0.6 "	0.6 "	0.2 Danger.	2.2 "	1.7 "	1.4 "
250 Ft.		Batter Brace.	0.8 Danger.	1.4 Danger.	0.3 "	0.4 "	1.3 Danger.	1.5 "
		1st M. Diagonal.	0.9 "	0.4 "	0.5 Safety.	0.3 Danger.	0.3 "	0.7 "
		2d "	0.9 "	0.9 Safety.	1.7 "	1.3 "	0.8 Safety.	0.1 "
		3d "	0.9 "	2.5 "	3.1 "	2.1 "	2.7 "	1.1 Safety.
		4th "	0.3 "	5.5 "	5.5 "	2.4 "	5.9 "	3.1 "
		1st Counter.	1.9 Safety.	11.1 "	9.9 "	1.4 "	11.8 "	6.8 "
		2d "	5.9 "	20.9 "	17.0 "	1.7 Safety.	22.9 "	13.0 "
	1st Top Chord.		0.4 "	0.2 Danger.	0.8 "	0.6 "	1.1 Danger.	1.5 Danger.
	2d " "		0.5 "	0.1 "	0.6 "	1.1 "	0.6 "	1.3 "
	3d " "		0.7 "	0.1 Safety.	0.5 "	1.6 "	0.0 "	1.2 "
	4th " "		0.5 "	0.1 Danger.	0.1 Danger.	1.9 "	0.3 Safety.	1.5 "

TABLE I—*Continued.*

Span Length.	Chord Members.	Web Members.	CLASS Z.			CLASS U.		
			Equivalent Uniform System.	Single Excess System.	Double Excess System.	Equivalent Uniform System.	Single Excess System.	Double Excess System.
300 Ft.		Batter Brace.	0.4 Danger.	1.4 Danger.	0.3 Danger.	0.7 Safety.	1.5 Danger.	1.3 Danger.
		1st M. Diagonal.	0.6 “	0.9 “	0.2 Safety.	0.1 “	0.8 “	0.8 “
		2d “	0.6 “	0.0 “	1.1 “	0.7 Danger.	0.3 “	0.5 “
		3d “	0.9 “	0.8 Safety.	1.8 “	1.5 “	0.6 Safety.	0.1 Safety.
		4th “	1.0 “	2.0 “	2.9 “	2.3 “	1.9 “	1.0 “
		5th “	0.7 “	4.1 “	4.7 “	2.8 “	4.1 “	2.5 “
		1st Counter.	0.4 Safety.	7.5 “	7.5 “	3.0 “	7.4 “	4.7 “
		2d “	1.9 “	12.5 “	11.2 “	2.5 “	12.9 “	8.0 “
	1st Top Chord.		0.1 Danger.	1.1 Danger.	0.1 Danger.	0.7 Safety.	1.4 Danger.	1.4 Danger.
	2d “ “		0.5 Safety.	0.5 “	0.4 Safety.	1.0 “	1.2 “	1.4 “
	3d “ “		0.7 “	0.3 “	0.4 “	1.6 “	0.6 “	0.9 “
	4th “ “		0.7 “	0.3 “	0.3 “	1.8 “	0.4 “	1.0 “
	5th “ “		0.6 “	0.4 “	0.1 Danger.	1.8 “	0.3 “	1.3 “
400 Ft.		Batter Brace.	0.1 Danger.	1.3 “	0.3 “	0.7 “	1.5 “	1.1 “
		1st M. Diagonal.	0.2 “	1.1 “	0.0 Safety.	0.4 “	1.2 “	0.8 “
		2d “	0.4 “	0.7 “	0.4 “	0.2 Danger.	1.0 “	0.7 “
		3d “	0.5 “	0.3 “	0.8 “	0.8 “	0.7 “	0.5 “
		4th “	0.8 “	0.1 Safety.	1.2 “	1.4 “	0.3 “	0.2 “
		5th “	0.9 “	0.6 “	1.8 “	2.0 “	0.3 Safety.	0.3 Safety.
		6th “	1.1 “	1.4 “	2.5 “	2.6 “	1.1 “	0.9 “
		7th “	1.0 “	2.5 “	3.5 “	3.2 “	2.3 “	1.8 “
		1st Counter.	0.8 “	4.1 “	5.0 “	3.9 “	3.6 “	2.7 “
		2d “	0.7 “	6.0 “	6.6 “	4.7 “	5.6 “	4.0 “
		3d “	1.3 Safety.	10.5 “	10.5 “	4.9 “	9.0 “	6.1 “
	1st Top Chord.		0.1 “	1.1 Danger.	0.1 Danger.	0.7 Safety.	1.5 Danger.	1.2 Danger.
	2d “ “		0.3 “	0.9 “	0.1 Safety.	0.8 “	1.4 “	1.1 “
	3d “ “		0.6 “	0.7 “	0.2 “	0.9 “	1.3 “	1.1 “
	4th “ “		0.6 “	0.6 “	0.2 “	1.3 “	1.2 “	1.1 “
	5th “ “		0.6 “	0.6 “	0.2 “	1.4 “	0.9 “	0.9 “
	6th “ “		0.6 “	0.6 “	0.1 “	1.4 “	0.8 “	0.9 “
	7th “ “		0.6 “	0.6 “	0.1 Danger.	1.4 “	0.8 “	1.1 “
	Bottom “		0.1 Danger.	1.3 “	0.3 “	0.7 “	1.5 “	1.1 “

TABLE II.

Table Showing Percentages of Error in Moments at Centers of Plate-Girder Spans Found by Equivalent Uniform, Single Excess, and Double Excess Systems.

SPAN LENGTH.	CLASS Z.			CLASS U.		
	Equivalent Uniform System.	Single Excess System.	Double Excess System.	Equivalent Uniform System.	Single Excess System.	Double Excess System.
15 Feet.	None.	14.0 Safety.	14.0 Safety.	None.	19.9 Safety.	19.9 Safety.
20 "	"	7.8 "	7.8 "	"	11.8 "	11.8 "
25 "	"	4.2 "	4.2 "	"	5.3 "	5.3 "
30 "	"	2.1 "	2.1 "	"	1.2 "	1.2 "
35 "	"	0.7 "	0.7 "	"	1.3 Danger.	1.3 Danger.
40 "	"	0.5 "	0.5 "	"	2.3 "	2.3 "
45 "	"	0.3 "	0.3 "	"	2.8 "	2.8 "
50 "	"	0.0 "	0.0 "	"	3.2 "	3.2 "
60 "	"	0.4 Danger.	0.4 Danger.	"	2.7 "	2.7 "
70 "	"	0.1 Safety.	0.1 Safety.	"	2.2 "	2.2 "
80 "	"	0.0 "	0.0 "	"	1.9 "	1.9 "
90 "	"	0.1 Danger.	0.1 Danger.	"	1.7 "	1.7 "
100 "	"	0.9 "	0.9 "	"	1.2 "	1.2 "

TABLE III.

Table Showing Percentages of Error in End Shears Found by Equivalent Uniform, Single Excess, and Double Excess Systems.

SPAN LENGTH.	CLASS Z.			CLASS U.		
	Equivalent Uniform System.	Single Excess System.	Double Excess System.	Equivalent Uniform System.	Single Excess System.	Double Excess System.
15 Feet.	None.	1.9 Safety.	22.5 Danger.	None.	45.4 Safety.	3.0 Danger.
20 "	"	6.0 "	16.7 "	"	33.3 "	10.0 "
25 "	"	7.6 "	13.2 "	"	22.8 "	12.3 "
30 "	"	5.8 "	12.8 "	"	18.1 "	13.3 "
35 "	"	2.8 "	13.9 "	"	14.3 "	14.3 "
40 "	"	1.7 "	13.8 "	"	12.0 "	14.4 "
45 "	"	0.7 "	13.5 "	"	10.5 "	14.1 "
50 "	"	0.6 "	12.5 "	"	9.5 "	13.5 "
60 "	"	0.5 "	7.8 "	"	7.9 "	8.4 "
70 "	"	1.5 Danger.	6.8 "	"	4.0 "	7.6 "
80 "	"	3.2 "	6.6 "	"	0.7 "	7.9 "
90 "	"	4.3 "	6.4 "	"	1.5 Danger.	8.0 "
100 "	"	5.1 "	6.4 "	"	2.7 "	7.9 "

2. That there is no combination of a constant car load per lineal foot and a single concentrated load which will give for all members of trusses and floor-systems, stresses which will agree even approximately with those found by the concentrated wheel load method.

3. That even if for any system of loading two separate single concentrations be adopted, one for floor systems and the other for main truss members, the said single concentrations cannot be adjusted so as to give results agreeing sufficiently well for practical purposes with those found by the concentrated wheel load method.

4. That if two engine excesses placed about fifty feet apart at panel points be adopted in connection with a constant car load per lineal foot, the stresses obtained thereby in members of floor systems and trusses do not agree sufficiently well for practical purposes with those obtained by the concentrated wheel load method.

The present status of this question of equivalent live loads for railway bridges is as follows:

1. The great majority of bridge engineers are in favor of abandoning the cumbersome method of concentrated wheel loads, and of substituting therefor some easy method which will give results practically identical with those found by the said concentrated wheel load method.

2. Of those bridge engineers endorsing this change, the great majority are in favor of adopting what has been termed the "Equivalent Uniform Load Method," involving the use of curve diagrams; the minority preferring the "Single Concentration with Constant Car Load Method," or, for short, the "Single Concentration Method."

3. It appears from the correspondence which I have had that many of the gentlemen who favor the last mentioned method do so principally because the loadings can be easily retained in the mind. They all appeared to think it practicable to establish, instead of any system of engine and car loads, a single concentrated load, which combined with a constant car load per lineal foot, will give practically equivalent results for all members of all spans. None of them claimed to have proved this; so, now that I have shown it to be impossible, they may favor the "Equivalent Uniform Load Method."

4. The principal reason why the "Equivalent Uniform Load Method" is preferred by a large majority of bridge engineers is because the work in making stress computations by its use is only half of that involved in making them by either the single or the double concentration method, and only a very small portion of that involved by the elaborate method of wheel concentrations.

5. A large majority of those railroad engineers who are interested indirectly in bridges are willing to concede to bridge engineers in this

matter of the substitution of an equivalent loading for that of wheel concentrations, provided they can be sure that the results obtained by the said equivalent loading agree closely enough for all practical purposes with those found by the "Concentrated Wheel Load Method." And it appears by the balloting that railroad engineers in general are greatly in favor of the "Equivalent Uniform Load Method."

In view, therefore, of the preceding, it does not appear unreasonable to conclude that the engineering profession is about ready to

1. Adopt a system consisting of a few standard train loads instead of the almost innumerable ones now in use; and

2. Employ equivalent uniform loads instead of the wheel concentrations and car loads of the "Standard" for computing stresses in bridges.

Very respectfully yours,

J. A. L. Waddell.

EDITORIAL.

We do not desire to enter into a controversy in regard to this matter for the simple reason that the game is not worth the candle. Mr. Waddell has shown a commendable zeal in his persistent attempt to displace the locomotive concentration system of loading by something better. We agree with him in everything except his conclusions regarding the single (or double) concentration system of computation. Apparently he has used the same concentration for all lengths of span below one hundred feet. It would be difficult to suggest a more erroneous or even grotesque method of application of the single concentration method. Obviously a short plate-girder span ought not to have a concentration in addition to its uniform load greater than the actual total locomotive load that can be placed on it; yet unless we quite misunderstand what Mr. Waddell has done, his results include a number of such absurdities, using that word in its logical sense. We fear, therefore, that the effects of the "personal equation" have not been entirely "nullified."

Percentages of variation of the results for the pin spans for the different systems of computation, even with the values taken by Mr. Waddell, do not differ essentially from each other, except in the matter of the counters and one or two adjacent small web members, and such differences are of no practical consequence. Hence his "conclusions" regarding the uniform load with one or two concentrations are not proved; indeed, they are without any real foundation whatever. It has been most conclusively shown that the so-called "equivalent loads" will give results near enough to the ideal for all practical purposes, but that is all. This we have never denied; it was evident without so much figuring. We have never made as a "claim" the observation that the single system with uniform loads would give as accurate results as the equivalent uniform loads, although we believe there is practically no difference, and nothing has yet been shown to the contrary. On the other hand, we have distinctly claimed that any pos-

sible difference between the two systems, in this respect, is of no consequence, and we still make that claim.

Again, we have frequently observed that any proper system of computation should provide for the locomotives running at any point in a train, and Mr. Waddell has said that his "equivalents" provide for that condition of loading. From the explanation of his tables it does not appear clearly that this has been done. We notice that Mr. Waddell again falls into the error of stating that the labor of computation of the single concentration method is twice that required by the method of uniform loads. It scarcely seems necessary for us to repeat our denial of that statement, but the evident error lies in the fact that the labor required by a single load computation is to that required by a uniform load approximately as unity is to the number of panels in the span contemplated.

Finally, the wholesale interpolations between the classes "Z" and "U" do not seem to us to be the best way of getting close values for such a wide range of computations, although we do not suppose the resulting errors are very great.

Extract from *The Railroad Gazette* of August 25, 1893:

STANDARD LIVE LOADS FOR RAILROAD BRIDGES.

KANSAS CITY, MO., Aug. 11, 1893.

To the Editor of The Railroad Gazette.

In your issue of July 28 you published, in direct sequence to a paper of mine on the "Live Load" question, some editorial comments thereon by the *Engineering Record*. Now, I ask you to publish simultaneously with the *Engineering Record* the following answer to their editorial comments:

This idea of using a single or double concentration in connection with a constant car load per lineal foot, as an equivalent for a train load of two locomotives with cars, has been held by a small minority of engineers interested directly or indirectly in bridge designing, and has acted as a stumbling block in my path ever since I undertook the investigation. It seems to me that I have proved conclusively that there is not a single point in favor of using the "Concentration System" (either single or double), and that it is inferior in every respect to the "Equivalent Uniform Load System."

The only idea ever advanced which showed any good reason for adopting the single or double concentration system is that an engineer having no books or papers at hand could carry in his mind such a simple loading as, for instance, a car load of 3,000 pounds per lineal foot combined with a single concentration of 30,000 pounds, while he could not remember the equivalent loads for the various spans. My latest investigations and the discussions thereon, however, have brought out the fact that, as far as floor systems and plate girder spans are concerned, the concentration must vary for each span length, consequently the benefits to be derived from the supposed simplicity of the loading vanish.

J. A. L. WADDELL.

KANSAS CITY, MO., August 11, 1893.

To the Editor of The Engineering Record:

Sir—Your editorials of July 8 and 29 on the subject of "Moving Loads for Railway Bridges" place me in a false position; therefore I trust that you will permit me to reply to them in your columns.

In your editorial of June 3 upon the same subject you write thus:

"A uniform load with a single concentration at its head or at any point can be made to cover every possible supposition of loading or length of span without any juggling with an equivalent device and with approximations at least as close to the ideal concentration stresses as those of the equivalent uniform loads and possibly more so."

It was this statement which induced me to make the calculations and write the letter that appeared in your issue of July 29, in which I showed the said statement to be incorrect.

Now in your editorial of July 29 you remark as follows:

"We have never made as a 'claim' the observation that the single system with uniform loads would give as accurate results as the equivalent uniform loads, although we believe there is practically no difference, and nothing has yet been shown to the contrary. On the other hand, we have distinctly claimed that any possible difference between the two systems, in this respect, is of no consequence, and we still make that claim."

It seems difficult to reconcile these two editorial statements.

Again, referring to the first quotation here given, is not any reader justified in assuming that the "concentration" which you endorse is intended to be a constant for each train load? If not, why the reference to there being "no juggling with an equivalent device?" But, judging by your editorial of July 29, you have concluded that it is necessary to vary the value of the concentration with the span length for floor systems and plate girder spans. It seems to me that this requires what you term "juggling."

My latest investigations have shown the following:

First.—That the concentration method will not give satisfactory results for end shears on plate girder spans. (See Table III., p. 567, *Engineering Record.*)

Second.—That if the concentration method be adopted for moment computations for floor systems and plate girder spans it will be necessary to vary the value of the concentration for each length of span.

Third.—That if the concentration for trusses be taken as constant for any one loading, the variations from exactness for main web members will be in general from two to ten times as great as the corresponding variations from exactness caused by the use of the "Equivalent Uniform Load Method." This was shown very clearly in Table IV., which, unfortunately for my side of the question, you did not find space to insert in your issue of July 29. As it bears upon the subject in hand, I shall ask you to be so kind as to insert it here, together with the following short explanation that I gave as to how it was prepared:

"In order to eliminate the 'personal equation' entirely in comparing the three methods, Mr. Hedrick has prepared Table IV., in which for each span considered, and for both 'Class Z' and 'Class U,' he has collected the greatest summations of percentages of error for both chords and webs, counters being ignored. When the extreme errors are of opposite kinds their arithmetical sum is taken, but when they are of the same kind their arithmetical difference is taken in determining the 'summation.' A study of Table IV. shows that, as far as chord stresses are concerned, there is but little to choose from between the three methods, but that in respect to web members the equivalent uniform load method is very much more accurate than either the single excess or the double excess method."

TABLE IV.

Table showing variations in percentages of error, as given by equivalent uniform, single excess, and double excess systems.

SPAN LENGTH,	MEMBERS	CLASS Z.			CLASS U.		
		Equivalent Uniform System.	Single Excess System.	Double Excess System.	Equivalent Uniform System.	Single Excess System.	Double Excess System.
100 ft.	Chord.	4.6	5.0	. . .	6.7	7.5	0.4
	Web.	7.0	15.6	7.6	6.3	18.5	6.5
150 ft.	Chord.	0.2	0.2	1.4	2.0	2.2	0.2
	Web.	4.8	12.7	9.1	2.5	14.4	7.7
200 ft.	Chord.	0.3	0.3	1.1	1.5	1.6	0.4
	Web.	1.9	8.9	7.0	2.6	9.7	5.8
250 ft.	Chord.	0.3	0.3	0.9	1.3	1.4	0.3
	Web.	0.6	6.9	5.8	2.8	7.2	4.6
300 ft	Chord.	0.8	0.8	0.5	1.1	1.1	0.5
	Web.	0.6	5.5	5.0	3.5	5.6	3.8
400 ft.	Chord.	0.5	0.5	0.3	0.7	0.7	0.3
	Web.	1.0	3.8	3.8	3.9	3.9	2.9

Now, supposing that the Single Concentration System were adopted, let us see what it would be necessary to do.

First.—A diagram of total end shears such as I have prepared for the "Equivalent Uniform Load System" would have to be used; because for end shears on plate girder spans no satisfactory results can be found by either the "Single Concentration System" or any other "equivalent" system of loading.

Second.—For moment computations for floor systems and plate girder spans it will be necessary to have a table or diagram to show how the value of each concentration varies with the span length. Then to find the bending moment at mid-span it would be necessary to apply the formula $M' = \frac{1}{4} Cl$ where C is the concentration and l the length of span, and the formula $M'' = \frac{1}{8} wl^2$, where w is the constant car load per lineal foot, then add the two results thus, $M = M' + M''$ = total bending moment due to live load. In comparison with this process, that for the "Equivalent Uniform Load System" appears very short. It consists simply in finding from the diagram the value of w', the equivalent uniform load per lineal foot, and substituting it in the equation

$$M = \tfrac{1}{8} w'l^2.$$

Now as far as the floor system and plate girder spans are concerned, does not this verify my statement that the amount of computation required by the "Single Concentration System" is double that required by the "Equivalent Uniform Load System," even if the value of the concentration were constant?

Again, does it not appear absurd to figure moments by the use of, first, *a variable concentration,* and, second, a constant car load; then add the results together, when the final result can be obtained by a single computation, using the variable equivalent uniform load per foot given by a diagram?

As for the use of the "Single Concentration Method" for trusses, I admit, and have heretofore admitted, that although by no means as accurate as the "Equivalent Uniform Load Method," it is nevertheless good enough for all practical purposes, especially as its errors can, if desired, be all made to lie on the side of safety.

But, again, why do double work in computation? And this brings me once more to one of the main points on which we differ. You have twice contradicted my statement that the "Equivalent Uniform Load Method" requires only one-half the figuring that the "Single or Double Concentration System" does. I have just proved the correctness of this statement as far as floor systems and plate girder spans are concerned. It therefore remains for me to prove it for trusses.

Let us divide trusses into two groups, those with parallel chords and those with broken top chords, and assume for convenience what in general is true, viz., that the panels are of equal length. In the first case the stresses are usually found by formulæ, and in the second case by graphics. In the first case, when the "Single or Double Concentration System" is adopted, the stress in each diagonal, post, and chord section must first be calculated by formula for the uniform car load, and afterwards also by formula for the concentration, after which the results are to be added together; while, when the "Equivalent Uniform Load System" is used, the stress in each member is found at once by formula, using an equivalent uniform load given by diagram instead of the car load employed in the first mentioned method. Is it not evident that fully twice as much work is involved by the former method as is involved by the latter? Let us take a practical case for example, viz., the diagonal in the *n'th* panel of an *n* panel truss. By the "Single Concentration Method" the stress is found by the formula

$$s = \frac{n' (n' + 1)}{2n} w\, l \sec \theta + \frac{n'}{n} C \sec \theta$$

while by the Equivalent Uniform Load Method it is given by the formula

$$s = \frac{n' (n' + 1)}{2n} w' l \sec \theta$$

As these formulæ are standard, there is no need to explain the meaning of the terms.

Now for the case of broken top chords. Using the "Concentrated Load Method," the stresses are first found graphically by one operation for the inclined end posts, and all the chord sections with a uniform car load over the whole span; then also by graphics the stress for each chord member from the concentration, which must occupy a different position for each panel length of either chord; and finally the advancing load web stresses are found graphically for the combined uniform car load and concentration.

In using the "Equivalent Uniform Load Method," the stresses on inclined end posts and all chord sections are found graphically by one operation for an equivalent uniform load over the whole span, and afterwards the advancing load stresses on web members are found graphically by employing the same equivalent uniform load. Now, although in either case the work of computing web stresses may be shortened materially by employing the method of an assumed end reaction, which I proposed in my paper on "Some Disputed Points in Railway Bridge Designing." nevertheless it will be found from actual experience that the shifting of the concentration for each chord section (especially where two concentrations are employed), will add so much to the labor of computation that the total amount thereof will be for the "Concentration System" fully twice that required for the "Equivalent Uniform Load System."

In your editorial of July 29th you make a statement which appears to me very curious. You say, "But the evident error lies in the fact that the labor required by a single load computation is to that required by a uniform load approximately as unity is to the number of panels in the span contemplated." Do you mean to say that in a twenty-panel bridge, with a broken top chord, it will take twenty times as much labor to compute all the chord and web stresses due to a uniform load per lineal foot as it would to compute all the chord and web stresses due to a single concentrated load which has to be shifted from one panel point to another, not only for each web stress, but also for each chord stress?" If you will tackle the actual problem you will find that the single concentration will involve quite as much figuring as will the uniform load per lineal foot.

In both of your July editorials you place considerable importance upon the fact that cars should precede as well as follow the engines in determining stresses in chord sections, and raise a doubt about my having taken account of this, so I shall now explain in detail my method of computing the equivalent load of any span.

I first find the moment for each chord section by the exact method of wheel concentrations, *but placing cars ahead as well as following the locomotives,* and for each moment thus found I compute the equivalent uniform load; then by the same exact method, but with no cars preceding the locomotives, I calculate the shear on each web member and determine the equivalent load therefrom. Finally, I take the average of the equivalents thus found for all chord and web members of the span as the equivalent uniform load for that span. The effect of considering cars preceding, as well as following the locomotives, is to give a better agreement for the "Equivalent Uniform Load System" than would have been found by having no cars ahead of the locomotives.

But why quibble over such an unimportant matter as this—you, especially, who make so little of large variations from theoretical exactness! That the whole subject is of no practical importance can be readily seen by an inspection of Table I. on p. 135 of your paper. Look at the errors in chord stresses for all three methods of computation and see how small they are! In "Class Z" the average errors for all the chord sections of all the spans given in that table are only 0.74 per cent. for the "Equivalent Uniform Load Method," 1.28 per cent. for the "Single Excess Method," and 0.41 per cent. for the "Double Excess Method"; and, what is still more to the point, there is very little variation from these averages, the errors occurring with surprising regularity and uniformity. In "Class U" many of the errors are about twice as great as those for "Class Z," but still very small. Is it not evident, therefore, that in deciding about the merits of the different systems chord stresses are out of the question, and consequently that your insinuation that I have ignored the effect of cars preceding as well as following the locomotives would be without force *even if it were true?*

In your editorial of July 8th you say: "We also infer from his present communication that the extra loads for end shears for short spans, which were prescribed in his original paper, are now discarded in favor of a new system of equivalent uniform loads, inasmuch as he says that "the equivalent loads on my new diagrams belong to all spans from 10 feet upward."

The changes in this particular which I have made since writing my original paper are simply the adding of certain very heavy alternative axle loadings to my proposed standard, and the plotting of the exact end shears on a diagram instead of indicating them approximately by a rather awkward formula. I am a firm believer in the principle that a change in the right direction is always in order, and am only too glad to receive from other engineers suggestions which will effect improvements in my work.

In conclusion I desire to say a few words of comment on the closing remark of your last editorial, viz.: "Finally, the wholesale interpolations between the classes 'Z' and 'U' do not seem to us to be the best way of getting close values for such a wide range of computations, although we do not suppose the resulting errors are very great."

This, Mr. Editor, is "the most unkindest cut of all." You have never even seen my curves, and you have not investigated at all concerning the exactness of the interpolation. When I tell you that Mr. Hedrick and I checked and counterchecked the results of the interpolation without finding any error which would be appreciable on the diagram, you will understand that this adverse criticism was uncalled for.

I regret exceedingly the unfavorable comments which you have given my work on the subject of "Standard Live Loads for Railway Bridges" and "Equivalent Uniform Loads," because any editorial utterance from such a high authority as your paper inevitably carries great weight, and the result will be to block me, at least temporarily, in this arduous task that I have undertaken solely in the interests of the civil engineering profession. Had you shown me to be in the wrong in a single point, I would most gladly have acknowledged my error; for I am one of those who, in scientific discussion especially, do not believe in arguing for mere argument's sake, or to maintain one's point after convincing reasons to the contrary have been advanced. But in this case I see no cause to withdraw in the slightest degree from any position that I have taken.

Thanking you, Mr. Editor, for your courtesy in publishing this letter, I remain,

Very respectfully yours,

J. A. L. WADDELL.

DISCUSSION

By J. A. L. WADDELL

ON

THE DETERMINATION OF THE SAFE WORKING STRESSES FOR RAILWAY BRIDGES OF WROUGHT IRON AND STEEL

By E. HERBERT STONE, C. E.

FROM THE
TRANSACTIONS
OF THE
AMERICAN SOCIETY OF CIVIL ENGINEERS
June, 1899.

INTRODUCTORY NOTES.

The stresses caused by the impact of a moving load may be very small or may be approximately as great as those produced by the load when statically applied, but we are still very much in the dark regarding the laws of variation. We know that the impact stresses due to a locomotive coming upon a small or light bridge at a high rate of speed are very great, and that they decrease materially as the span increases in weight and length. We know also that the stresses increase with the speed of the train, but the ratio of increase is undetermined.

The moving load causes vibration as well as impact; and vibrations set up heavy but indeterminate stresses, the amount of which is dependent upon the speed of the train, the relation between the weight of the load and that of the structure, the forms of the members, the character of the details, and the design of the bridge as a whole.

When we think of these considerations and recall the facts that minor secondary stresses are not calculated, that the amount and frequency of wind stresses are almost unknown, and that there are great variations in the strength of the material employed, it would seem that the proportioning of the members of a railway bridge must be largely a matter of conjecture. But it must not be forgotten that we have had the opportunity to study for many years the action of bridges under load and to judge of their efficiency and durability. This opportunity has not been wasted, and the result is a substantial basis for judgment relating to permissible and economical stresses. As we have not established the laws of the variation of stresses, we probably have not reached the true limit of economy in design; for good judgment dictates that we use ample metal to assure safety. We have, however, attained some idea of the variation, enough to enable us to establish formulæ which probably bear some relation to the truth and enable us to simplify the labor of computing sections.

Railway managers are coming to understand the importance of exact knowledge of impact stresses, and are placing in the hands of their engineers the means and facilities for making tests. The work has been carried on very unsystematically so far, however, and the results are of correspondingly small value, but enough has been done to lend encouragement to the hope that some broad-minded management like that of the Pennsylvania Railroad Company will appropriate sufficient funds to conduct exhaustive tests and determine the laws of impact once for all.

Owing to the death of the general manager and a general change in the officers of the railway, the proposed tests mentioned by Dr. Waddell in

De Pontibus and in the following discussion on Mr. Stone's paper on "Working Stresses for Railway Bridges" have never been made, and the prospect of their being made is now remote.

Dr. Waddell and his partner, Mr. Ira G. Hedrick, have, however, made a considerable number of experiments to determine the effect of impact in producing deflection of spans as a whole. The apparatus, which was designed by Mr. Hedrick and constructed under his direction, registers the deflection at a given point on the span, first with a static load, then with the moving load on the bridge. The deflections are, of course, proportionate to the chord stresses, hence, since the stresses under the static load are known, those due to impact may be readily determined.

This instrument has been used mainly upon overloaded spans of antiquated types, consequently the results of the tests are of small value. One curious discovery was made, however, which justifies Dr. Waddell in his frequent condemnation of cylinder piers for railway bridges. In testing bridges for a Southern railway the instrument was applied to several spans which had been built by one bridge company from the same drawings. and it was found that the deflection due to impact of the spans resting on cylinder piers was double that of the spans resting on masonry, thus proving conclusively that the vibrations due to the lack of rigidity in the piers act to increase the stresses in the spans.

The greatest value of impact so far obtained by means of the apparatus is fifty per cent. of the live load, while the ordinary value is about twenty per cent. This large value was obtained on an old deck, fish-bellied, open-webbed, riveted girder span that was so badly designed that it was condemned on sight and ordered supported by trestle bents until it could be replaced. The calculations made later showed that the girders were seriously overstrained by primary stresses alone.

Tests on such structures prove nothing, yet Messrs. Waddell and Hedrick have not had the opportunity to test modern, scientifically designed spans. In fact occasion for use of the instrument is so rare that there is small hope of obtaining important data by means of it. It is noteworthy, however, that in the tests made so far the increments of stress are not always proportionate to the increase in train speed.

The use of the Frankel extensometer promises to furnish reliable data regarding the impact stresses in individual members of bridges, which are, of course, the data most to be desired. The few sporadic tests that have been made in this country with it are valuable, but nothing less than a comprehensive plan, including tests conducted by competent engineers upon a wide range of lengths and types of structures, with trains moving at various speeds, will determine satisfactorily the law of impact on railway bridges.

Until this law is determined bridges must continue to be proportioned according to the rules laid down by the most expert bridge specialists. It is impossible and undesirable that the element of judgment should ever be eliminated, but it is to be hoped that the day is not far distant when we shall have well-substantiated data from which we may determine what are the maximum safe stresses for railway bridges.

DISCUSSION OF MR. STONE'S PAPER ON "WORKING STRESSES FOR RAILWAY BRIDGES."

By J. A. L. Waddell, M. Am. Soc. C. E.

The subject of Mr. Stone's paper is one in which the writer for many years has been deeply interested, and concerning which on several occasions he has written; consequently it behooves him to discuss the paper.

The subject relates to one of the most important unsolved problems in the engineering profession, because, unless we are straining steel for all bridge members of all spans just about right, we are either wasting metal or encroaching on the ultimate danger limit in making bridge designs. The principal thing that we need to know is to what extent the metal in the various members of all approved types of modern bridges is strained by moving loads applied at different velocities, and the relation of the effects of loads so applied to those of the same loads applied statically.

If such data were obtained there could readily be constructed a diagram of percentages to add to live load stresses that are determined on the assumption of static application of loading, which would cover the combined effects of impact and vibration, both of which tend to increase the actual intensities of working stresses. The addition of these percentages would reduce the total stresses to equivalent static stresses, and would permit the adoption of one or two unit working stresses of each kind for designing. An allowance for unavoidable, small secondary stresses could either be included in this percentage diagram, or else this feature could be taken care of in determining the intensities of working stresses to use with equivalent static stresses.

The results of deflection observations on Indian bridges quoted by Mr. Stone are certainly both interesting and valuable; but it is doubtful whether they will apply satisfactorily to modern American bridges, because the types of structures used in the two countries are so different. On this point the writer can speak authoritatively, having for the last twelve years been a constant reader of *Indian Engineering*, the representative technical paper of India. Speaking generally, the weight of metal in an Indian bridge exceeds that in a corresponding American bridge of the same span and loading by from sixty to one hundred per cent. This does not mean that the Indian bridge is so much stronger, stiffer, or better, but that the extra metal is simply wasted, its only good function being to absorb the impact. Such a result can be obtained just as well by using a less expensive material than steel, for instance stone ballast in the floor.

Again, Indian bridges are much more shallow than American bridges, and have far shorter panels and many more parts.

The writer has reason to think that the Indian experiments were made mainly upon spans as a whole and not upon their component members; consequently the results will apply to chords only and not to webs; for the writer does not agree with Mr. Stone in his statement that "the results obtained from the deflection of the truss, as a whole, must to a great extent represent the average for all of its members."

Not only are hangers and other light web members much more subject to shock than are heavy chords, but also the light and panels of a bottom chord are probably somewhat more affected by impact than are the heavier chord members at and near mid-span. Experiment alone will determine the truth of this and settle the vexed question of what are the various intensities of stress caused by live loads applied dynamically.

In respect to this question of impact, the writer has expressed himself as follows in his lately issued work entitled "De Pontibus":

"The uncertainty as to the magnitude of the effect of impact on bridges has for many years been a stumbling-block in the path of systematization of bridge designing, and will continue to be so until some one makes an exhaustive series of experiments upon actual intensities of working stresses on all main members of modern bridges of the various types. The making of these experiments has long been a dream of the author's, and it now looks as if it would amount to more than a mere dream, for the reason that the general manager of one of the principal Western railroads has agreed to join the author in the making of a number of such experiments on certain bridges of the author's designing, the railroad company to furnish the train and all facilities and the general manager and the author to provide the apparatus and experimenters. It is only lack of time that has prevented these experiments from being made this year, and it is expected that they will be finished in 1898. It is hoped that the result of the experiments will be either to determine a proper formula or curve of percentages of impact for railroad bridges, or else to inaugurate a series of further experiments that will determine it.

"Meanwhile the author has adopted temporarily the formula,

$$I = \frac{40,000}{L + 500},$$

in which I is the percentage for impact to be added to the live load, and L is the length in feet of span or portion of span that is covered by the load.

"This formula was established to suit the average practice of half a dozen of the leading bridge engineers of the United States, as given in their standard specifications, and not because the author considers that it will give truly correct percentages for impact.

"In spite of all that has been said to the contrary in the past or that may be said in the future, the impact method of proportioning bridges is the only rational and scientifically practical method of designing, even if the amounts of impact assumed be not absolutely correct, for the method carries the effect of impact into every detail and group of rivets, instead of merely affecting the sections of main members, as do the other methods in common use.

"The assumption made in some specifications that the live load is always twice as important and destructive as the dead load, irrespective of whether the member considered be a panel suspender or a bottom chord bar in a 500-foot span, is absurd, and involves far greater errors than those that would be caused by any incorrectness in the assumed impact formula.

"The author acknowledges that he anticipates finding the values given by the formula somewhat high; but it must be remembered that the formula is intended to cover in a general way, also, the effects of small variations from correctness in shop-work, or to provide for what the noted bridge engineer, the late C. Shaler Smith, used to term the factor of ignorance."

At present it looks as if the proposed little series of tests for 1898 referred to will have to be postponed, owing to want of time and funds for apparatus.

The ideal way to make a proper series of tests on actual intensities of working stresses for bridge members is to find some broad-minded, liberal American millionaire who would be willing to devote from $100,000 to $200,000 of his surplus cash to the experiments, then have an advisory committee of, say, five prominent bridge engineers retained on fees large enough to cover simply their actual cash expenses, to formulate and systematize the work, and to direct a working committee of three well-paid engineers who would devote their entire time and energies to the investigation. Two members of the latter committee should be experienced experimenters and the other an expert bridge engineer.

The first step to be taken should be the determination of exactly what is to be ascertained and the *modus operandi* for doing the work. The next should consist of experiments on the various kinds of apparatus for measuring extensions and compressions of members, and deflections and vibrations of spans, so as to decide upon what kinds of apparatus to employ and how to use them.

Next would come the making of the series of tests, and lastly the compilation of results and the drawing of final deductions.

Most of the experimenting should be confined to modern structures of the most approved type; but, if time and funds permit, some work should be done on bridges of the older types, many of which are still in common use, although no longer built.

The beneficial results of such a series of tests are so apparent that it would be useless to discuss them. It is the writer's intention to continue advocating the making of such experiments until they are inaugurated and completed, provided that he live long enough.

The writer is surprised to see how large a portion of the paper Mr. Stone devotes to iron bridges, which are now a thing of the past, and how small a portion to steel bridges. The benefits to be derived from impact investigations are confined almost entirely to future bridges, which certainly will be of steel, because the practical railway engineer, in determining whether it is safe or not to continue to use an existing bridge, bases his judgment mainly upon the action of the structure under load, the excellence or weakness of its details, and its location in respect to traffic and shock, as well as upon the intensities of working stresses to which it is subjected.

It is questionable whether Mr. Stone's method of tabulating or plotting his percentages of increase for live load stresses upon the basis of ratio of dead and live load stresses is as correct or scientific as the more usual manner of basing them upon length of span covered by moving load; certainly it is by no means as convenient for the computer, who does not care to spend any more time than he can help in figuring ratios of loads, when he can find the percentage by simply glancing at a diagram after noting the length of span to be covered for the greatest stress on the piece considered. In respect to the correctness of Mr. Stone's method let us assume an extreme case for comparison, viz., a 200-foot span of ordinary type and a 100-foot span so overloaded with ballast floor as to make the ratio of dead and live loads the same for the two spans. Would it be better to use the same percentage of increase for these two bridges or to make it greater for the short span than for the long one? Most engineers would certainly adopt the latter method.

The writer has never yet been convinced of the applicability of the results of the investigations by German scientists on fatigue of metals to the proportioning of bridges. In order to obtain any results at all, those scientists had to strain the metal far beyond the elastic limit and had to apply the loads every few seconds, while in bridges the metal never is (or more strictly speaking never should be) strained much higher than about one-half of the elastic limit, and the loads are applied at much longer intervals, thus giving the metal a chance to recover itself and return to its original state before the application of another load.

The determination of the value or values of intensities of working stresses is purely a matter of professional judgment based upon experience in the field, and should not be relegated to scientists in their laboratories.

If we recognize that the elastic limit is the true criterion of ultimate strength, and if we strain no higher than one-half of this amount for equivalent static stresses due to ordinary loads, and 30 per cent. additional for same due to an unusual or practically impossible combination of all loads, including wind pressure, we shall be allowing sufficient margin to cover small secondary stresses, possible flaws in the metal and occasional dropping below average in elastic limit.

For medium steel having an ultimate tensile strength (measured on specimens) between 60,000 and 70,000 pounds per square inch and a least elastic limit of 35,000 pounds per square inch, the writer in his latest specifications (De Pontibus, Chapter XIV.) strains eyebars 18,000 pounds per square inch and built members in tension 16,000 pounds per square inch.

Mr. Stone evidently has more faith in metal than the writer, for he strains soft steel having an average ultimate strength of 54,000 pounds per square inch just as much as the writer does the medium steel. It is true that Mr. Stone counts upon 36,000 pounds per square inch as the elastic limit of such soft steel, but the writer's experience in the use of metal does not indicate that it is safe to rely upon more than 30,000 pounds per square inch as the elastic limit of such metal, to say nothing of the probable decrease in full-size members as compared with test specimens. Moreover, standard specifications for soft steel allow the elastic limit in specimen tests to run generally as low as 30,000 pounds per square inch and sometimes even down to 27,000 pounds.

Referring to the last table in Mr. Stone's paper, as a matter of curiosity the writer has made a comparison of the "nominal stresses" involved by using the impact formula and intensities of De Pontibus with those given by Mr. Stone, employing as a basis the bottom chords of single-track railroad bridges.

The results of the comparison are given in the following table.

Span in Feet.	Live Load.	Impact.	Dead Load.	Nominal Intensity.	Stone's Nominal Intensity.	Percentage of Difference.
100	4,266	2,844	1.630	12,144	12,758	+ 5.1
150	4,144	2.550	1,850	12,621	13.220	+ 4.7
200	4,030	2,303	2.130	13.102	13.720	+ 4.7
250	3.930	2,096	2.444	13,546	14,193	+ 4.8
300	3,860	1,930	2,820	13.966	14,655	+ 4.9
350	3.800	1,788	3,165	14,322	15,021	+ 4.9
400	3.760	1,671	3.500	14,631	15.312	+ 4.7
450	3.730	1,571	3.860	14,914	15,581	+ 4.5
500	3.700	1,480	4.226	15,169	15,815	+ 4.3
550	3,680	1.402	4,576	15,389	16,011	+ 4.0
600	3,660	1,331	4,930	15.585	16,178	+ 3.8

Average difference = + 4.6

It will be noticed that Mr. Stone strains his soft steel "nominally" about four and a half per cent. higher than the writer strains his medium steel, and that the variation in this difference is in all cases less than one per cent. The latter fact tends to show that, although bridge engineers may differ considerably in their methods of reaching certain conclusions, some of the results at which they arrive may not vary materially.

ADDRESS

TO THE

GRADUATING CLASS

OF THE

SCHOOL OF ENGINEERING

OF THE

UNIVERSITY OF KANSAS.

JUNE, 1893.

INTRODUCTORY NOTES.

The address to the Graduating Class of the School of Engineering of the University of Kansas in 1893, consists of some practical advice to young men about to enter upon their professional work. It is as pertinent to-day as it was eleven years since and should help the fledgling to settle numerous points of considerable importance to him. It is generally true that advice is rarely followed, even when it is given in a strictly personal way, and it is well that this should be so, for every one must ultimately act upon his own responsibility. There are many general principles, however, which may be brought to the young man's attention and which he will find exceedingly valuable in assisting him to reach his own decisions. The advice which simply directs that this or that be done often does more harm than good, for, the reasons being absent, it must be followed blindly. The best kind of advice is that which appeals directly to the reason, states causes, modifying circumstances, and effects, and leaves action to the judgment. In all that he said on this occasion Dr. Waddell followed this plan.

Very generally the student looks upon his education as a means of increasing his earning capacity and is exceedingly impatient if his initial position brings him a very small salary. To point out the advantages of work which brings experience, with often little else, in comparison with well-paid positions is of no small service to the embryo engineer. It will probably save him much discouragement and lead him to adopt the right course, for very often the young man makes serious mistakes because he has a very narrow view, or none at all, of the life of a professional engineer. He does not know what to expect and his strife for advancement is without definite method or purpose. He changes employment, not for broader experience, but with the vague hope of increasing his salary or gaining a more favorable opportunity. Dr. Waddell has offered in this address some very clear glimpses of what is to be expected in the way of money and experience from the various kinds of work the new graduate is likely to obtain and has rendered no inconsiderable service by doing so.

ADDRESS TO THE GRADUATING CLASS OF THE SCHOOL OF ENGINEERING OF THE UNIVERSITY OF KANSAS.

In an address like this, it is, I suppose, in order for me to give to you, who are about to undertake the duties of practical life, some good advice based upon my personal experience, which, by the way, covers about eighteen years of practice in various branches of engineering, including that of civil engineering education. Unfortunately, it is a fact that, in general, people are more fond of giving advice than of taking it; and I have found on a number of occasions that advice given to students was unheeded. It is an old saying that each one must "dree his ain weird," and there is a great deal of truth in it; nevertheless I have seen occasions when advice from older men was eagerly sought after and appreciated when given. To many minds the receiving of advice and acting upon it is an indication of mental inferiority, or at least of a lack of strong-mindedness; but I have noticed that the individuals who are governed by such ideas generally make a failure in both professional and business life. Self-reliance is a very good thing, if not carried too far, and, in fact, is an essential to success in any calling; nevertheless, its possession should not debar one from profiting by the experience of others.

I can look back to a portion of my life when some sound, practical advice from an older engineer would have been of the greatest benefit to me, in that it would have been the means of preventing me from wasting considerable valuable time, simply because I did not know how to employ it advantageously.

Let me hope, then, that my words to-day will not be entirely wasted, but that some of you will benefit by them, and that in the years to come I shall occasionally run across one of you who will tell me that my advice was good, and that it has proved useful to him.

Please remember that it is based upon my personal experience as well as upon observation of the careers of others, and that it is drawn from both successes and failure; because there is always a great deal to be learned about "how not to do it." Please remember, also, that I am in great sympathy with students of civil engineering; for at heart I am still a professor, and some day after I have earned sufficient money in the practice of engineering to permit me to indulge in such extravagance, I would like to again occupy a professor's chair. To my mind there is no more useful or higher branch of the engineering profession than that of instruction, notwithstanding the openly avowed opinion of many practising engineers to the contrary. It is not sufficient, though, to recognize for oneself the equality of professors and practising engineers; but it is necessary to make the world at large acknowledge the fact. Steps in this direction, I am happy to say, are now being taken; and to-day the professor of civil engineering takes higher rank in the American Society of Civil Engineers than he did a few years ago.

But to return to the subject in hand, viz., advice to young engineers. On account of the kindly feeling I entertain toward all engineering students, especially those who are earnest and ambitious, I shall speak to you very freely and openly, giving you of the best that I have, even if by so doing I lay myself open to adverse criticism.

But to accomplish what I have in mind I must drop all formality in addressing you, and meet each of you as man to man upon a most intimate footing—in fact I must speak as if I had known each one of you for years and had taken a personal interest in your welfare. I shall take it for granted that you will permit this liberty, and shall govern myself accordingly.

But in following this method I shall have to reduce my address to a rambling discourse, ruining it perhaps as far as elegance is concerned, but at the same time rendering it the more useful.

As Commencement Day approaches, each engineering student of the graduating class, as soon as he has assured himself of his graduation, begins to think more and more of the work that he shall do after finishing his course of study, and of the position that he will obtain. He naturally gauges the positions that he hears of by the amount of salary offered in each case; and strives to obtain the one to which the highest salary is attached. In so doing he makes a fundamental and most serious mistake, because the true ultimate value of any position offered to a newly fledged engineer is an inverse function of the salary paid. This sounds, perhaps, like a very strange and wild statement, but it is nevertheless a true one;—let us look into the matter a little, and perhaps you will agree with me. The highest salary in this country paid to young engineers immediately after graduation is, as far as my experience goes, one hundred dollars per month; and this amount is given only in very flush times when there is a great demand for assistants in the field. To earn such a salary at the start, the young engineer must be already well posted on the practical part of the work in addition to being versed in the theory. Now what practical work is there on which students are posted? Why, simply elementary surveying! Consequently the fortunate or unfortunate young man (according to the point of view of the person considering the case), who receives one hundred dollars per month to begin with, will have his attention confined to the laying out of town lots for speculators or to surveying farms; and how much, pray, is to be learned on that kind of work? Something, of course, because no one can do work of any kind without increasing the amount of his knowledge and experience; but how little it is in comparison with what is to be learned in the higher branches of engineering! Again, what future prospects are there in such work as surveying? It is seldom indeed that a surveyor makes more than a bare living, and when times are bad the young engineer engaged in this line is very likely to lose his position or have to spend many idle days without pay.

Railroading offers a better field to the recent graduate than does land surveying, and at the same time the pay is fair. For instance, any man on a railroad survey can really earn for his employers forty or fifty dollars per month besides the cost of his subsistence, even if it be only dragging chain or driving stakes; because the life is a hard one physically, and manual labor can always command a certain amount of pecuniary compensation. But the young engineer who works in a subordinate position on a railroad survey will have to spend a great deal of time in a manner that is profitable to his employers, but not so profitable to himself. He will be gaining some experience, of course, but not the greatest possible amount or the highest grade of experience. Notwithstanding this, I believe there is no more attractive opening, and oftentimes no more truly profitable one, to the recent graduate than a position on a railroad survey. Coming as he does from a sedentary life, and too often worn out both physically and mentally by overwork, the active exercise in the field proves to be exactly what he needs; and after a few days, when the physical exhaustion attendant on unaccustomed bodily exercise has passed away, he feels like a new man, the mere acts of living and breathing become a pleasure, the sun appears to shine more brightly than it has shone for years, and he experiences a new phase of existence. Such a life is most seductive, and unless one is careful, it is apt to divert his tastes and ambitions from higher to lower things. The truly ambitious young man can, however, improve his time in such a position by picking up stray bits of knowledge here and there, not only on his work, but by conversation with the other members of the party.

An experience of this kind at the outset of one's career will give him a taste for out-of-door life which he will retain as long as he lives. On this point I speak from personal experience; for shortly after graduating I took a position on the Canadian Pacific Railway that caused me to spend eighteen months in the wilderness to the Northwest of Lake Superior, where, in addition to my strictly professional duties, I had to work harder physically than any day laborer in civilization. Now, strange to say, there is no portion of my professional career to which I look back with as much pleasure as I do to those eighteen months spent in the wilds. There is something peculiarly attractive and inspiriting in such a rough life, with its hard work, long tramps through the swamps in summer and on snow shoes in winter, its hardships, which include coarse and sometimes not overplentiful food, uncomfortable lodgings (generally consisting of a leaky tent carpeted with hemlock boughs to serve as a couch), innumerable insect pests, wet weather in summer and extreme cold in winter; its jolly evenings spent over the camp fire, where past experiences in bush-life are narrated, and even its dangers, which give spice to the whole life. Such dangers were by no means imaginary; as many a poor fellow has lost his life in that country through forest fire, severe cold (the temperature often passing below the freezing point of mercury), drowning by falling through the ice of early winter, or by the capsizing of a canoe; or worse still through being lost in the woods and perishing slowly from starvation.

This early experience of mine in railroading, together with still earlier experiences in camping out, gave me such a taste of bush life that even today I would rather spend one month in hunting and fishing among the Rocky Mountains than twelve months on a pleasure trip in Europe.

But to return to the question of compensation for services immediately after graduation. There are various lines of engineering where an inexperienced man can earn a living at office work, but the pay is necessarily small; because the work can be done by cheap draftsmen who are content to accept a small wage, and are in truth generally worth no more than they get. Such positions will eventually lead to something higher, but the young engineer will be compelled to do a great deal of drudgery in order to earn the money which his employer pays him. In any case, though, an engineer needs sufficient experience in drafting to enable him to learn how to put his ideas on paper rapidly, and how to make a presentable drawing, consequently such experience is beneficial; but one should avoid having too much of it, in order not to become a mere drafting machine.

But now let us suppose that our new alumnus enters the office of an engineer who is doing a large amount of practical work in one of the higher branches of engineering, what do you suppose his services are really worth to his employer? Candidly, except in most uncommon cases, they are worth absolutely nothing; yes, oftentimes less than nothing, because not only has a great deal of his work to be done over again, but also his employer has to devote considerable time to his instruction in fundamental principles and practical methods, one day of which time is worth in dollars and cents more than a whole month of the young man's services. But see what the young man is gaining—not a day, not an hour passes without his learning a number of valuable principles, facts and methods, so that at the end of a month he will have acquired a greater amount of valuable knowledge than he would have obtained in a year when working on a fair salary at routine work. In such an office the newcomer who has had no practical experience seldom receives any salary; and the time is not far distant when in this country an inexperienced young man will have to pay for the privilege of working in such an office. This has been the custom for many years in England, but it is a custom that has been abused by the employers, who have thus brought the system of apprenticeship into ill repute.

And now have I said enough to convince you of the correctness of my statement that "the true ultimate value of any position offered to the newly fledged engineer is an inverse function of the salary paid"? I shall leave each one of you to answer this question for himself, after thinking over at his leisure what I have said on the subject.

Now let us take up the question which each of you has undoubtedly propounded to himself many times of late, viz., "What branch of engineering shall I adopt as my life's work?" You have found it a difficult one to answer—have you not? I do not see how it could well be otherwise; for you have as yet had very little opportunity to see what the various branches of the profession are like, and of what their work consists. Some of you may be able to answer the question to-day to your satisfaction, or at least you may think you can, but the majority of you have been unable to make up your minds. In my opinion, it is not advisable for you to try to do so at present. This is no time for you to choose a specialty; and even if you do choose one, you ought not to settle down now to practice it to the exclusion of all other work. The old definition of an engineer, viz., "a man who knows a great deal about something, and something about everything," was not a bad one, and still holds good even in these days of specialties. There is no branch of engineering that is separate and distinct from all other branches, consequently the more general the experience obtained in youth, the greater will be a man's capacity and the broader his mental grasp during his best working years. On this account I would advise all of you, who can afford to do so, to spend a few months, or at most a year, on one class of work, mastering as many details as possible, then drop it and take up another branch, and so on until you have obtained a wide, comprehensive, and thorough experience in general engineering. Meanwhile, make up your mind as to what specialty you will choose, or at least as to what line of engineering you will follow; and as soon as you have decided finally, let your studies and practice tend continually more and more toward that chosen line, until eventually you abandon all others for it and make it your life's work. Be content for a while to earn a bare living, provided that you are obtaining the experience you desire. If you do this, take my word for it, you will find that at middle life you will outrank professionally those who started in with you but who adopted the policy of confining themselves to one line of work and thought, thus rendering themselves men of one idea or rather one set of ideas.

Some of you, perhaps, on account of pecuniary obligations, contracted in obtaining your education, or family responsibilities, cannot take this advice; but will have from force of circumstances to settle down in one place with the object of earning as quickly as possible an income that will suffice to pay off your indebtedness or maintain your family. If there be any of you so situated, I would urge upon you the importance of extensive technical reading in other branches of the profession than the one in which you engage, in order that you may prevent yourselves from becoming fossilized and incapable of taking interest in anything outside of your special line of work.

To all of you I would say, " Don't leave school with the idea that you have completed your technical education; for, no matter how thorough your course may have been, your technical education has merely begun." It is true that you have had enough book learning to enable you to earn a living without further study, but you can never attain professional distinction without continuing your studies. I recognize the fact that it is quite difficult to carry on a course of technical reading when one has to work long hours in either the office or the field, but I have proved by personal experience that it is practicable. The method that I adopted was to take a certain treatise, mathematical or otherwise, and arrange to read it through thoroughly and understandingly in a certain number of days, laying out beforehand the amount of each day's reading, and basing it upon the average time that I had to spare and the character of the book. If for any reason I failed to complete the reading allotted for any day, I read an extra amount the next day, and sometimes read ahead of my allowance so as to anticipate possible interference with my plans. In this way I accomplished the entire reading in the allotted time; and it paid. It is a good practice to carry in one's pocket some technical book to read at odd moments, for instance, during the noon hour in the field or while waiting for a railway train or even while traveling on the cars, although I cannot really commend the latter practice because of its injurious effect upon the eyes.

It is essential that you read the principal technical newspapers and periodicals in order to keep abreast of the times, also the transactions of the leading engineering societies, especially those papers therein which treat of subjects allied to your line of work. There is one point on which I wish to caution you, viz., that an article is not necessarily valuable because it is composed wholly or partially of mathematics. As a rule, most of the mathematical papers on engineering subjects that one runs across are mere rubbish; but occasionally a really good mathematical engineering paper appears; and this ought to be read. After a little experience you will find no difficulty in sifting the wheat from the chaff. Do not misunderstand me in this matter of mathematics, for I would be the last one to advocate abandoning the study of that science after graduation. I merely wish to warn you against wasting valuable time on investigations which are too often based on false assumptions, or that treat of matters which could be settled more simply in some other manner.

In determining upon a course of reading, one should not confine himself entirely to technical books and papers, but should choose some standard literary works for the purpose of improving his style in writing; for, alas! it must be confessed that most writers on engineering subjects have a great deal to learn concerning correct literary style.

In my opinion, it is the duty of each member of the engineering profession to add his mite to engineering literature; although one should never write a book or paper merely for the sake of producing something. The most valuable information that the profession possesses is to be found in papers published by engineering societies, and describing works completed, the difficulties encountered during construction, and the methods adopted for doing the work. Each of these papers, together with the discussions evoked by them, not only marks a step in constructive progress, but also indicates how the next steps should be taken. Abstract papers or those of a generalizing nature are also of the greatest value; but there are only a few men who are competent to prepare such papers, consequently their number should be limited. It takes a bold man to write such a paper; and he is likely to get into trouble because of it, so I would advise you to confine your literary efforts to descriptions of work done or the treatment of minor details until your experience has accumulated sufficiently to warrant you in an endeavor to generalize.

In preparing engineering papers, cultivate a clear, terse, and concise literary style, so as to express your ideas in the fewest words consistent with a due consideration for fluency and elegance of diction. Cut out all padding from your writings, because engineers are too busy to spare time to read anything that is unnecessary. The proper age at which to commence writing technical papers is not easy to fix, but in general it is safe to advise that one's early efforts be presented to minor or local engineering societies; then if these be well received, future papers may be presented to the engineering periodicals or to the national engineering societies. There is nothing which a young engineer can do that will advance his professional standing so much as the writing of a good, sound technical article for publication; and there is nothing that he can do which is more detrimental to his reputation than to write an incorrect or weak one. When contemplating the writing of a paper, it is a good plan to ask oneself these questions: "Is this paper really needed?" "will it fill a gap?" and "will it prove useful to the profession?" If the answers be in the affirmative, write the paper; if not, don't.

As for the writing of a technical book, better postpone such work until you have had at least eight or ten years' experience; and do not even then undertake it, unless you see that there is a need for such a treatise as you contemplate writing, and that you have exactly the right information to present to the profession.

While it is true that there are a great many technical books published which should never have been written, it is equally true that technical literature is far behind engineering practice, and that there never was a time when sound engineering treatises, prepared by thoroughly posted, practical and educated writers, were as much needed as they are to-day. You see, therefore, that for those of you who have literary tastes and tendencies, there is plenty of occupation ahead. Unfortunately, there is no money to be gained directly in such work; but on the other hand there is reputation to be made, and that means eventually money, although, it is a mistake to connect the two at all closely even in one's thoughts. Professional reputation in itself ought to be sufficient incentive for a young engineer of the right sort; but the fact that the obtaining of it will ensure pecuniary success is undoubtedly an extra stimulus to exertion.

Let me advise you to pay special attention to the study of specifications and contracts for engineering works, and to learn how to prepare them for yourselves. You can learn readily the style of such documents, but it takes years of experience to enable one to prepare them so that they shall cover the entire ground in a perfectly satisfactory manner. The more experienced an engineer the more thorough will be the specifications that he writes; but from this it does not follow that in comparing specifications prepared by two engineers their values will vary directly as the amounts of experience of the writers; because some engineers seem to be unable ever to learn to write good specifications. This is due to a want of literary training in their early education; and a most deplorable and grievous fault it is.

Post yourselves on legal decisions of interest to engineers, and let some of your miscellaneous reading include the laws of contracts.

Study business methods as much as possible, and learn how accounts should be kept. These things are important, and they need not demand very much time; because with all the mental training you have had, and will have in your practice, you ought to grasp readily all such comparatively simple matters. A good way to master them is to consult with men of business, bookkeepers, etc., with whom your work throws you in contact. They can show you often in a few minutes what might take you hours to study out by yourselves.

And here let me give you a little piece of sound advice. Never be too proud to learn from the most ignorant. Even the navvy who handles a pick and shovel can give a young engineer valuable information concerning earthwork; and the stonecutter and quarryman will generally be found well posted on many matters of importance in masonry construction that are not treated in the text books.

Whenever you have an opportunity, study how to manage men, and how to get the greatest amount of useful work out of the workmen. A little tact will often accomplish results that could not be obtained in any other way than by its use. While it is necessary to be firm in dealing with workmen, and in fact with all employees, it is well to treat them reasonably and not to lay down the law too severely. The better the understanding between employer and employees, the greater will be the amount of work accomplished.

Post yourselves concerning the money values of all kinds of engineering construction; nothing gives the general public more confidence in an engineer's ability than to perceive that he is well versed in the cost of all kinds of work.

Immediately after graduating each one of you should enter the American Society of Civil Engineers as a Junior, and should get his grade advanced to that of Associate Member, and finally to that of Member, as soon as he can qualify. As a member of any grade in that Society you have the right to take part in the discussion of any paper, and to present to the Board of Direction for acceptance any paper of your own. You are also entitled to receive the *Transactions* of the Society and to attend all of its meetings.

If you are stationed for any length of time in any city, where there is a local engineering society, it will pay you to join it, and to take as active a part in the proceedings as your practical experience will warrant.

You will find that all through life it will pay you to make for future reference systematic notes concerning not only your own work, but also that of others; but to be of any practical value these notes should be transferred from time to time to an index book, so that any particular subject can at any time be found without delay. It is very important to know where to look for any required published information, and for this the various indices which have recently been issued will be found valuable.

After finishing any large piece of work, and while it is still fresh in your mind, it is well to write out an epitome of knowledge gained on it, indicating the methods used, improvements to be made in them on future work of a similar character, mistakes to be avoided, etc., then have a number of copies of this struck off on a typewriter to keep for future reference for yourself and perhaps for others.

In my practice I have found it very convenient to carry in the pocket a note book for recording "things to be done," so that whenever a new idea strikes me, or when I think of something that I wish to do, I make a note of it on a list; and whenever I finish doing anything so recorded I draw a line through the item. When the list becomes too much erased, I prepare a new one by collecting the items that have not been crossed out. By the use of such a list I find that I can accomplish a great deal more than I could had I nothing but my memory to rely upon; for when I have an idle minute, which, by the way, is not very often, I pull out my note book and see what there is that I can do. I would suggest that you give this method a fair trial.

Some engineers believe in keeping a diary. I do theoretically—but practically I have failed to keep one, although sometimes I wish I could remember what I was doing on a certain day, and cannot. It would be well to give the diary a trial also.

You will find as you go through life that earnestness of purpose is the main-spring of success, and that if you set your mind on attaining any object within reason, you will, if you keep on trying, eventually succeed in attaining it. I am a firm believer in the French proverb *"Tout vient à celui qui sait attendre,"* because I have tested it, and have never yet found it fail to be correct.

In all your work develop and employ constantly such a perfect system of checking and counter-checking as will render you as nearly absolutely proof against making mistakes as it is possible for fallible humanity to become. By so doing you will save yourselves infinite worry and trouble. I know of no more unpleasant sensation than that which one experiences immediately after ascertaining that he has made a blunder; and, moreover, the sensation does not pass away as quickly as one might wish. I have known cases in which the duration extended over years.

Do not be discouraged by failure, but endeavor to profit by it; and do not be afraid to tell brother engineers of your failures. It will do you no harm, and may do them good. It takes a brave man to acknowledge a mistake or a failure, but a man who is deficient in that kind of courage would do well to keep out of the engineering profession. Mistakes of both oneself and assistants are the *bête noire* of a conscientious engineer, but I find that the longer one is in practice the fewer mistakes will escape his observation.

Become acquainted with as many engineers as possible, and try to establish yourselves on such a friendly footing with a few prominent members of the profession that you can occasionally go to them for advice. It is a fact that if an engineer of established reputation takes a personal interest in any bright, active, energetic and ambitious young engineer, he can be of the greatest assistance to him, and can help him to advance with almost phenomenal rapidity in the profession.

Should you desire at any time to obtain some general knowledge that cannot be found in print, do not hesitate to ask other engineers for it.

The chances are that it will be given to you most cordially; for any professional man of the right stamp is always glad to help a brother engineer with advice and to give him the benefit of his greater experience. It may happen occasionally, though, that you will be snubbed. Unfortunately, one cannot make such a sweeping statement concerning engineers as it is customary to make concerning sportsmen, viz., that "all sportsmen are good fellows." I will say this, however, that as far as my personal experience is concerned "most engineers are good fellows," and I think you will find that there is less jealousy and more good fellowship among engineers than among the members of any other profession.

It is hardly necessary for me to touch upon the converse of this, viz., that you should be ever ready to aid a brother engineer in every way that lies in your power.

Avoid all petty professional jealousies, and remember that to rise in the world it is not necessary to push others down. If it were for no other reason than mere policy, it is generally better to say a good word for another engineer than to speak against him; but this is no reason for one's stultifying himself when asked if he can recommend for a position someone of whom he does not approve. It is too often the case that when an engineer is discharging an employee for whom he has no use, he gives him a written general recommendation, merely for the sake of parting pleasantly. This is a mistaken policy; because it tends to detract from the value of all written recommendations.

Assistants on engineering work may be divided into two classes, those who work for the almighty dollar, and those who, as it is termed, work for glory. Those of the first class adhere to certain fixed hours, and as soon as quitting time comes, or a little before, they get ready to stop work for the day. Moreover they always appear afraid of doing too much for their money. They reach the climax of their career when they obtain a position worth about five dollars per day. Those of the second class work more for the knowledge and experience to be obtained than for the salary, and seem to pay but little attention to office hours, continuing their labors far into the night when interested in what they are doing, or when there is any necessity for extra exertion. Such men rise steadily and often rapidly to responsible, well-paid positions; and the less they say about increase of salary the oftener it appears to be raised. It is unnecessary for me to advise you as to which of these classes you should join.

Of course there are times in a man's professional career when it may be advisable for him to assert himself and demand proper compensation for his services, if he thinks that they are not adequately remunerated; but this should not be during the first few years of his practice, when he is in reality serving his apprenticeship. Later on, especially after marriage, when the welfare and comfort of wife and children depend upon the amount of his earnings, it becomes a man's duty to look out for the dollars.

And this brings me to another point upon which I desire to touch, as it is an important one, viz., the best age for an engineer to marry. The young man who immediately after graduating rushes blindly into matrimony, regardless of how it will affect his professional career, makes a serious mistake; for the care of a family will prevent him from going from one class of work to another in order to obtain a varied experience, and will tie him hand and foot, necessitating his grinding day after day on work that perhaps he detests, and on which there is nothing more to learn, because the dear ones at home are dependent upon his daily earnings. If circumstances permit, it is well for the young engineer to wait until he is twenty-eight or thirty years old before he puts on the matrimonial yoke, but it is not advisable to delay much longer than this, if he intends to ever marry at all; because the longer he waits the more set in his ways will he become, which condition, as we all know, is not compatible with the principles of American home rule.

Let me take the liberty of advising you to endeavor always to save a portion of your earnings and to invest it in some good security which will bring you in a fair rate of interest. Any investment which promises more than six or eight per cent. should be looked upon with suspicion; for while one such scheme succeeds, three others will fail. You may consider me an authority on this point, as my experience is personal and has been paid for. It may be difficult to save money when one is traveling from place to place obtaining his professional training in the manner which I have suggested; but still it is practicable, even if the amount be as small as five or ten dollars a month. Here, too, I am speaking from experience, because as a young man I spent practically all I earned, and the time came when I wished that I had been more economical. After marriage you will find that this matter of saving money becomes an absolute necessity, so why not begin it at once? Remember that I do not advise niggardliness or parsimony; for such attributes are incompatible with American manhood; but on the other hand extravagance is unnecessary and uncalled for.

I would like to call your attention to a series of papers and discussions on the subject of "engineering ethics" which the technical press has been publishing lately. The importance of this subject cannot be over-estimated. The engineering profession needs a code of ethics in order to raise itself in the public opinion to the position it ought to occupy. I fear it is going to take time to establish such a code; but the day will surely come when we shall have one: and then our profession will be recognized as the highest of all, in that it takes the lead in the progress and development of the entire civilized world. Until this code be established, there is nothing for each of us to do except to have a little code for himself, consisting of a single principle, viz., "do the square deal by everybody under all circumstances." At times it may be difficult to decide as to what is exactly the best thing to do; but, if one uses his judgment and endeavors to put himself mentally in the other man's place, his decision cannot be far from right.

The engineer in charge of construction stands in a peculiar relation to both his employers and the contractors; and the true relation is not generally recognized. It is that of arbitrator, and not that of oppressor. No one who employs an engineer has a right to think that he purchases that engineer's conscience when he pays him his salary. It is as much an engineer's business to look out carefully for the rights of the contractor as it is to see that his employers receive the full value of what they pay for, and that all work is properly done. Believe me, no engineer ever yet made a success professionally by oppressing contractors. I consider it the engineer's duty to aid the contractor in every legitimate manner, and to save him expense whenever it is possible to do so properly. Unless a contractor be satisfied with the profit he is making out of a piece of work, the chances are that he will slight it. In letting work it never pays to award the contract to any competitor for less than actual cost plus a living profit. The older an engineer grows, the more convinced will he become of the correctness of this statement.

Let me again call your attention to the importance of systematizing your work. The most successful engineer is he who can obtain the greatest amount of correct work out of those whom he employs, and it is only by looking ahead and laying out systematically the work of each individual and of the entire corps that this can be effected.

Let me counsel each one of you to set for himself sooner or later an ultimate object to be accomplished, and let it be a great one, but still well within the realms of possibility; and let him ever strive toward its attainment. If he succeed, he will be well repaid by the satisfaction of feeling that he has done some material good for his fellow mortals; but if not, he will still feel that he has done his best, and that his life has not been spent in vain.

But after all, there are many important things in life for you other than professional advancement and success; although you may judge from my discourse that I have forgotten this, or that I do not even recognize it. Believe me, I would by no means counsel you to neglect the many social and other pleasures that are within your reach. It is bad policy to reduce oneself to a mere working machine; and, if you do, you will be sure to find that the machine is likely to break down or to run badly for want of a little lubrication. Every hard working man is entitled to an occasional holiday; and to do him the most good he ought to spend it in the manner which will afford him the most enjoyment. In the end, no time is lost; because the reviving effect of the vacation will enable him to work all the harder when he settles down to business once more.

Again, a man has certain obligations toward his fellow men; and one of the most important is that he make himself agreeable and entertaining when in company. This he cannot often do, if he be a mere drudge and a slave to his occupation.

In the rapid development of humanity which is taking place at the present time, it is necessary that each individual take a deep and absorbing interest in one certain subject; but it is equally important that the people as a whole concern themselves with a variety of subjects, thus necessitating that each individual have a number of topics in which he takes at least a passing interest.

Unless such were the case, the whole mass of humanity would be working without any coherent purpose, each unit being independent of all the others, and following a path of its own regardless of how that path interferes with those of the other units.

A professional man is liable, on account of the intense interest he feels in his work, to overlook these facts; and it is on this account that I make a point of advising each of you to mix as much as possible with his fellows, and to endeavor to make himself appreciated by them as something more than simply a hard-working engineer.

COMMENT.

The greatest mistake the recent graduate commonly makes is to consider his days of study over and to seek only to put into practice what he has already learned. If he enters the employ of some large manufacturing company, a bridge company, for instance, he will find himself in the drafting room engaged, first upon tracing and other simple work, then completing and tracing drawings the chief essentials of which have been laid down by some more experienced man, and, finally, laying out work for himself. His entire energy is spent upon the mechanical details of his work, such as the making of a neat drawing with good letters and figures, the placing of dimensions and notes, making out a bill of material, and learning standard gages, clearances. sizes of rivet heads, allowances for bending, and similar details. He works from general drawings on which stresses and sections and the general type of construction are all shown, leaving him little to think about but the location of rivets, the exact lengths and edge distances, and the technique of his drawing. All of his working hours are spent in the drafting room, and he will learn of shop methods only from the man who checks his work, unless he devotes his spare time to the inspection of the work in the shops. But it is the exception rather than the rule to find the young engineer engaged in the drafting room work who will spend more than a casual hour or two a week in the shops, though they are in operation at least two hours a day more than he is required to be in the drafting room. His study is dropped because the contents of his books help him little in his present work.

Thus he stagnates, grows lazy, forgets much of his school work, and gradually becomes a drudge. His salary slowly increases as he gains in skill as a draftsman until, at the end of four or five years he earns about thirty dollars per week. His knowledge of shop work accumulates until he knows enough of it to make a correct drawing, and that is about all he has to show for his years of work. He has gained neither position nor money nor engineering knowledge. From the professional point of view he is a failure.

It may be objected that this picture is overdrawn, but it is not. The average man who enters the employ of a large manufacturing corporation or a large construction company follows this course. The chief engineer of a prominent bridge company which employed about fifty men in the drafting rooms, most of them technical graduates, once required another designer; he gave every man of promise two or three weeks' trial in designing and estimating, yet found no one who was competent to take up the work with reasonable facility. The engineer in charge in large establishments is constantly searching for bright, energetic young men to fill positions of responsibility, for men who are willing, careful, and thorough are hard to find among the engineers who are employed in the drafting rooms.

It would thus appear exceedingly inadvisable for the recent graduate to enter the employ of such large establishments, but it is the men who are at fault, not the work. There is no better place for the right kind of a man to gain experience than in the shops, because the amount and variety of work he may see under construction is very great. If careful attention be paid to the work he is given to do, no matter how trivial or uninteresting it may be, more responsible work will be assigned to him as he shows his ability to do it. But aside from the experience he gains from his daily duties, he has the opportunity to learn how the work of the designing and estimating office, the business office, the various shops, and the erecting department is organized. He may also see how similar structures are designed by different engineers, what labor various specifications entail, what are the benefits of such requirements as sub-punching and reaming, assembling field connections, and milling to exact lengths. In fact, the opportunities to learn are discouragingly numerous.

It is not enough to see how work is done; that is valuable to know, but the reason why it is done so is the vital matter. The fear of being thought ignorant restrains many a young man from asking questions, and keeps him ignorant. An earnest and tactful search for information rarely meets with rebuffs, but a foolish, thoughtless questioner will soon become a nuisance. The men in authority encourage a novice who is anxious to learn and go out of their way to help him.

How full notes should be kept depends altogether upon the man and his mental methods. Too many notes take more time than they justify and bury the important matters in the trivial. But there are few men who are blessed with a good, clear memory for details. If a point be thoroughly understood it will probably be remembered without effort, but many points must be jotted down for further consideration.

The young engineer should subscribe for the principal technical periodicals which deal with his own and allied lines of work, even though they be available at his employer's office, as there is no better foundation for an engineering library than files of such papers. Two of the best American journals, one of the English, and one in each of the foreign languages with which he is familiar are well worth while. Four or five such periodicals will keep one abreast of the times and furnish much food for thought.

It is to be presumed that the recent graduate is already familiar with the best technical books relating to his line of work, though this is too rarely true, and the reviews in the engineering journals will furnish information regarding new books. The best of these should be purchased and read, even though authoritative works in the same lines are already in the library, for every good book contains much new matter.

It is broadening and restful to read books which treat of subjects related very distantly, if at all, to one's specialties or current work, and knowledge so acquired invariably becomes useful sooner or later.

The advertisements appearing in the technical journals merit almost as much attention as the text. The notices of lettings furnish samples of such documents, and the engineer must know how to draw them; and new machinery, new methods of construction, excellent illustrations of structures and machines, and much other valuable information may be found in the advertising columns.

Catalogues and descriptive pamphlets may generally be had for the asking and often contain much valuable data. The hand books published and distributed gratuitously by the manufacturers of structural steel, wrought steel pipe, fireproofing materials, cement, paint, concrete reinforcement, boilers, engines, stokers, and similar materials and machines are essential to the engineer. Often the information these books contain is superficial, sometimes it is misleading, and occasionally it is in error, hence it should be thoroughly checked and must always be used with discretion, but its high value is unquestioned.

All engineering data should be indexed as soon as it is obtained, for it is valuable only as it is available for use, and a mass of ill-arranged books and papers is a source of much annoyance. The aggregate time lost in hunting through them for desired information would suffice to index them many times over. The card index is by all means the best for the purpose, for, besides being more convenient to handle, it may easily be kept free from dead matter. When the amount of data on hand is small the index seems hardly worth while, but when the data have increased till the need of the index is felt, it is an appalling task to prepare it.

Membership in any grade in the national technical societies supplies valuable technical papers, lends interest in the profession, brings increased acquaintance, and altogether makes for advancement.

One of the greatest mistakes the young civil engineer makes is to confine his study to purely technical matters under the impression that business matters are foreign to his professional work. As a matter of fact, business comes first when he has sufficient technical experience to place him in a responsible position. If he engage in consulting practice it will require business ability to obtain engagements; if he enter contracting or manufacturing he must be a thorough business man or he will fail in the strife for contracts and orders.

Ethically engineering is not very different from any other vocation, but the general prevalence of envy and jealousy of the more successful men seems to be an especially common sin among the younger men. In the struggle for advancement the breadth and dignity of the profession are too frequently forgotten.

It hardly seems essential to point out that absolute integrity is quite as essential to the engineer as to the judge. Not many young men come to their work with tainted minds, but those who engage in contracting, either for themselves or in the interest of others, are especially exposed to temptation; and those who buy for their employers are in little better position. Unearned considerations are rarely offered openly or brazenly, but generally appear honest at first glance. And if the first step be taken, progress is easy and rapid. No compromise of any character should ever be considered, for it will readily lead to the ruin of the professional career. Every engineer should set himself the highest ideals and adhere to them rigidly. To proclaim them from the housetops is a bit unpleasant for his associates, however, and he will find discreet modesty invaluable.

What shall be his ultimate goal is a matter every engineer must decide for himself. The time is undoubtedly near when an engineering education will be considered the best training for manufacturing businesses, and many technical students will make no plans for a professional career. At present a great many engineers have abandoned purely technical work for managerial or administrative positions, and the number who do so is steadily increasing. Again, the young man's tastes and opportunities are rarely apparent in the beginning, consequently, the choice of a specialty is better left until considerable experience has been acquired. But when it is selected, it should be followed with the utmost zeal and constancy if the highest success is to be attained.

THE HALSTED STREET
LIFT-BRIDGE.

INTRODUCTORY NOTES.

When this country was little more than a great farm and manufactures were of small importance, the volume of traffic was comparatively small and the obstruction of navigable waterways by the ordinary rotating drawbridges was a matter of little moment; but the rapid strides made by the manufacturing interests, the growth in the size and number of cities, the advent of the electric railway, and the consequent development of city and suburban traffic, the increase in the value of property situated on the water front, and the enormous development of shipping, both by rail and by water, substantially prohibit the construction of any bridge that obstructs the channel or the adjacent property or that is not quick and certain in its operation. In the large Western streams which are little more than navigable in name the obstruction of the channel by the pivot pier of a rotating bridge is of no consequence; but in the narrow and busy waterways of the larger cities such obstruction is entirely inadmissible. The unequal-armed rotating bridge with a pivot pier at one edge of the channel interferes with the use of the adjacent wharf. This not only increases the initial expense, but, by decreasing the available wharfage, restricts the usefulness of the waterway. For these reasons it became imperative a few years since to develop some type of bridge which should leave the waterway and the wharfage unrestricted and which should, at the same time, be comparatively low in cost and sightly in appearance.

This demand led to the introduction at about the same time of several types of movable bridges, among which may be mentioned the "jack-knife draw," the folding lift-bridge with one tower, the "pull-back draw" in which the elevation of the center of gravity of the movable parts remained unchanged during the operation of the bridge, the rolling lift or bascule bridge, and the Halsted Street Lift-Bridge. Each type had its advocates, its points of superiority, and its weaknesses; but the test of time has relegated to oblivion substantially all of them except the bascule bridge. The design of this type has been improved until it satisfies the chief requirements for a movable bridge. It leaves the waterway unobstructed, does not interfere with adjacent property, presents a sightly appearance, may be constructed at a reasonable cost, is simple in construction and rapid in operation, and it closes the street or railway track automatically as the bridge is opened. The "jack-knife draw" was essentially lacking in rigidity and soon proved unsatisfactory, the folding lift-bridge was expensive to operate, and the Halsted Street type of lift-bridge proved to be high in first cost and expensive to operate.

The first cost of the Halsted Street Lift-Bridge, the only one of its type constructed, was extravagantly high, since Dr. Waddell has estimated that it could be duplicated for about seventy-five per cent. of the expenditure it involved. The bridge companies were inexperienced in the erection of such structures and were required by the city to guarantee the operation of the bridge, even though they were not responsible for the design, consequently, they tendered high to cover contingencies. Again, owing to the shortsighted economy of the city authorities, before tenders were invited borings were not made to determine the character of the earth on which the foundations were to be placed, hence it became necessary later to change the plans and let the contract for the work without competition. But with the best of management it is not probable that another lift-bridge of this type could be constructed as cheaply as a bascule bridge of the same span.

The chief reason, however, why it is improbable that another such structure will never be erected lies in the prejudice of the layman, the fear that the high towers will be blown over, that the ropes are not strong enough, and that sooner or later the span or the counterweights will fall. This fear is reflected by the newspapers and acts to prevent the authorities from contracting for any structure which has aroused such opposition. The public will traverse dangerous bridges daily without fear, for the structures are familiar and the danger is not understood; but any novel construction which appears to be unstable will excite violent opposition.

The Halsted Street Lift-Bridge is, however, a sightly structure and it has served its purpose well for more than ten years. Barring the effects of the neglect commonly allotted to public structures, it is in satisfactory condition and promises to fulfil its mission for many years to come. It is unique in the annals of bridge design and will long remain a monument to the courage and skill of its designer. Many of its details are valuable, and, like every other important structure, it contains many lessons for the thoughtful engineer. Therefore Dr. Waddell's description of the bridge and the discussions of other engineers which are to be found in the following pages are eminently noteworthy, aside from their historical value.

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THE HALSTED STREET LIFT-BRIDGE.

By J. A. L. Waddell, M. Am. Soc. C. E.

Read November 7th, 1894.

WITH DISCUSSION.

History.—For a number of years there was a rotating combination drawbridge over the South Branch of the Chicago River at Halsted Street, but on June 30, 1892, a vessel ran into it and knocked it down. When the city attempted to rebuild it, the lake navigation interests objected to having another rotating draw span at this crossing, on the ground that the pivot pier of the old bridge was always a serious obstruction to navigation; and they used such influence with the War Department that the city was restrained from building the structure as contemplated. The Commissioner of Public Works of Chicago at that time was the Hon. J. Frank Aldrich, who a few months later was elected to Congress. Mr. Aldrich was placed in a rather awkward predicament, for, on the one hand, the people of the district in the neighborhood of the Halsted Street crossing—which, by the way, is one of the greatest thoroughfares of the city—were clamoring for a bridge; and, on the other hand, the United States Engineer Corps would not permit him to build any structure which would narrow the waterway to any such extent as would a rotating draw span.

The folding bridge or "jack-knife draw," one of which was then under construction at another crossing of the Chicago River, was advocated by certain parties; but Mr. Aldrich, who is himself, or, perhaps, more strictly speaking, was, a civil engineer, did not consider this type of bridge sufficiently rigid for the long span and for the heavy traffic.

After making a thorough study of the problem, Mr. Aldrich decided upon building a lift-bridge similar to the one designed previously by the writer for the proposed crossing of the ship canal at Duluth; and after considerable delay permission was obtained from the War Department to build the structure, with the proviso, however, that the clear headway be increased from 140 to 155 feet above mean low water.

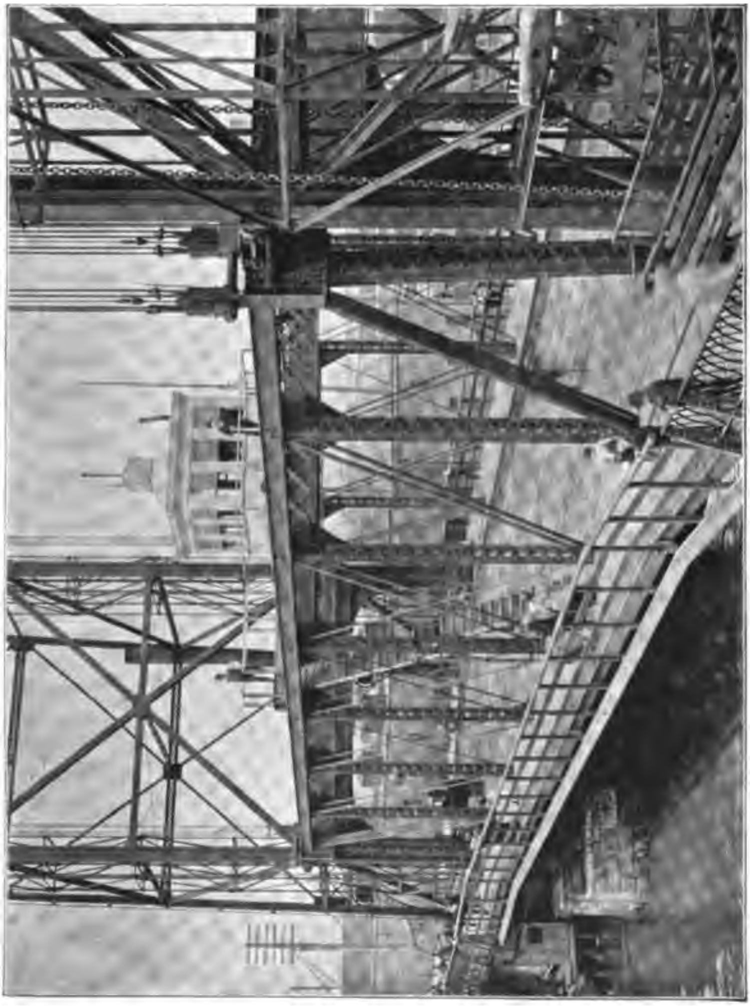
Before the demand for extra clear height was made, bids had been asked for, and the contract had been awarded provisionally, on schedule prices for materials in place, to the Pittsburgh Bridge Company (W. W. Curtis, M. Am. Soc. C. E., Engineer), with the Hale Elevator Company of Chicago as sub-contractors for the machinery, which latter company afterward transferred its contract to the Crane Elevator Company of the same city. But it was not until the beginning of 1893 that the contract for building the bridge was finally signed, sealed, and delivered. Even then the tribulations of those interested in the enterprise were not at an end, for the letting of the contract was irregular, in that there was no money in the City Treasury to pay for the bridge; therefore, according to the usual custom under such conditions, reliance was placed on the Finance Committee and Board of Aldermen voting, later on, the necessary funds. Under ordinary circumstances this irregularity would have done no harm; but in this case it was otherwise, because it gave each Alderman and each city official an opportunity to tie up the work, if he so desired, by alleging that the scheme was impracticable and that the bridge could not possibly work successfully. Continual worry was experienced on this account, and it is fair to say that to this circumstance is mainly due the great delay in completing the contract, which required fifteen months, instead of the six months allowed. In fact, it was at one time doubtful whether the sub-contractors for the machinery would ever finish their work; because they debated seriously whether it would not be better to lose about $15 000 which they had already spent rather than to complete the contract and take the chance of receiving nothing. This difficulty, however, was tided over by Mr. Curtis, who gave to his sub-contractors such satisfactory assurances that they would be paid eventually that they decided to proceed with their work.

Another main cause of difficulty and delay was the continual changing of city officials, for in the two years during which this bridge subject was on the *tapis* there were three changes of administration, involving the election or appointment of three Mayors, three Commissioners of Public Works, and three City Engineers, to say nothing of minor officials.

General Description.—The location of this bridge is very awkward, for not only does Halsted Street cross the river on a skew of 10½°, but there is an offset in it of 41½ feet just at the crossing. This combination involves a skew of 22½° for the structure in respect to the channel.

PLATE I.
TRANS. AM. SOC. CIV. ENGRS.
VOL. XXXIII, No. 742.
WADDELL ON HALSTED STREET LIFT-BRIDGE.

PLATE II.
TRANS. AM. SOC. CIVIL ENGRS.
VOL. XXXIII, No. 742.
WADDELL ON HALSTED STREET LIFT-BRIDGE.



By setting the main and rear piers on lines at right angles to the central plane of structure, the effect of the skew was taken out of the bridge and carried to the machinery house and the street retaining walls.

As shown on Plates I. and II. the bridge consists of a single Pratt truss through span of 130 ft., in seven equal panels, and having a truss depth of 23 ft. between centers of chord pins, so supported and constructed that it may be lifted vertically to a height of 155 ft. clear above mean low water. At its lowest position the clearance is about 15 ft., which is sufficient for the passage of tugs when their smokestacks are lowered. The span differs from ordinary bridges only in having provisions for attaching the sustaining and hoisting cables, guide rollers, etc., and in the inclination of the end posts, which are battered slightly, so as to bring their upper ends to the proper distance from the tower columns and their lower ends to the required positions on the piers.

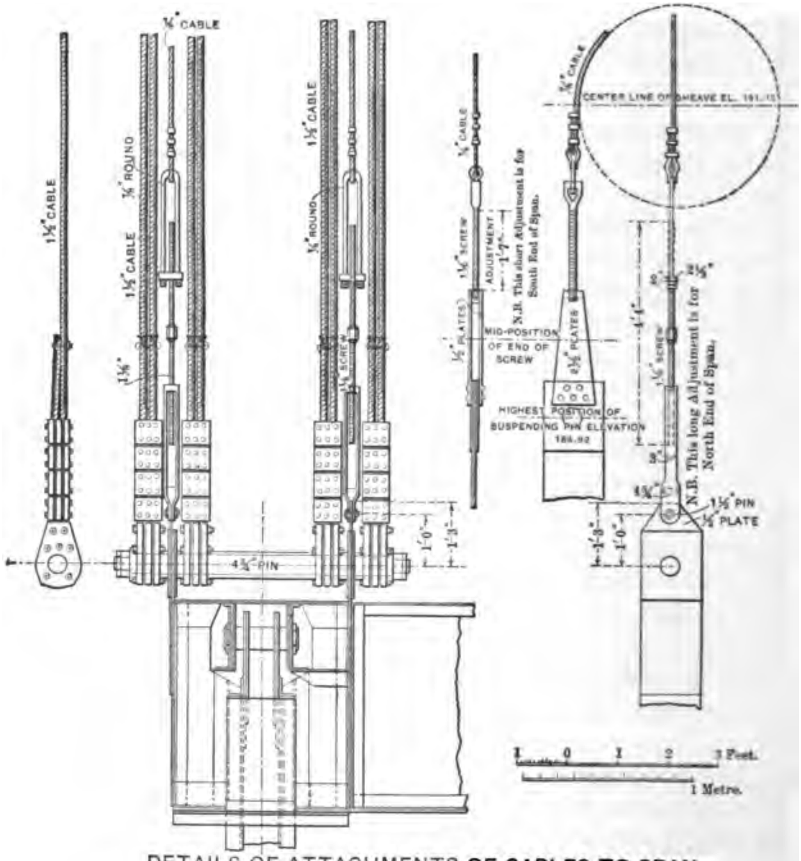
At each side of the river is a strong, thoroughly braced, steel tower, about 217 ft. high from the water to the top of the housing, exclusive of the flag poles, carrying at its top four built-up steel and cast-iron sheaves, 12 ft. in diameter, which turn on 12-in. axles. Over these sheaves pass the 1½-in. steel wire ropes (32 in all) which sustain the span. These ropes are double; *i. e.,* two of them are brought together where the span is suspended, and the ends are fastened by clamps, as shown in Fig. 1; while, where they attach to the counterweights, they form a loop, which passes around a 15-in. wheel or pulley that acts as an equalizer in case the two adjacent ropes tend to stretch unequally.

The counterweights, which are intended just to balance the weight of the span, consist of a number of horizontal cast-iron blocks about 10 x 12 in., in section, and 8 ft. 7 in. long, strung on adjustable wrought-iron rods that are attached to the ends of rockers, at the middle of each of which is inserted the 15-in. equalizing wheel or pulley previously mentioned.

The counterweights run up and down in guide frames built of 3-in. angles, as shown on Plate III.

The weight of the cables is counterbalanced by that of wrought-iron chains, one end of each chain being attached to the span, and the other end to the counterweights, so that, whatever may be the elevation of the span, there will always be the same combined weight of sustaining cables and chain on one side of each main sheave as there is upon its other side.

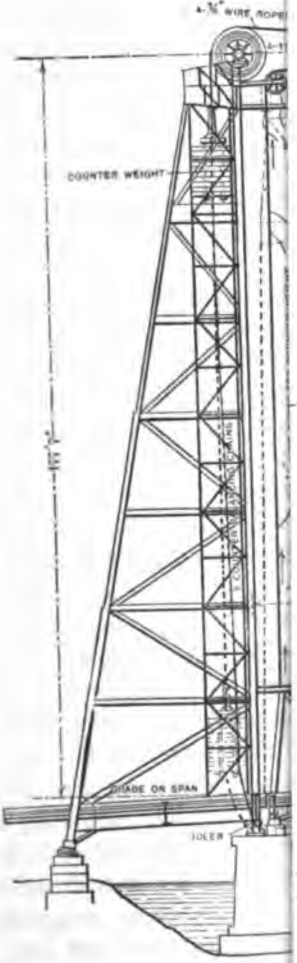
Between the tops of the opposite towers pass two shallow girders thoroughly sway-braced to each other and riveted rigidly to the towers. The main function of these girders is to hold the tops of the towers in correct position; but incidentally they serve to support the idlers of the operating ropes and to afford a footwalk from tower to tower for the use of the bridge tender. Adjustable pedestals under the rear legs of each tower provide for possible unequal settlement of the piers which support the tower columns. Each of these pedestals as shown on Plate IV. has an octagonal forged steel shaft, expanding into a sphere at one end, and into a cylinder with screw threads at the other. The ball end works in a spherical socket on a pedestal, and the screw end works in a female screw in a casting, which is very firmly attached to the bottom of the tower leg. By turning the octagonal shaft, it is evident that the rear column will be lengthened or shortened. The turning is accomplished by means of a special bar of great strength, which fits closely to the octagon at one end, and to the other end of which can be connected a block and tackle, if necessary. These screw adjustments were useful in erecting the structure, but it is quite likely that they will never again be needed.



DETAILS OF ATTACHMENTS OF CABLES TO SPAN.

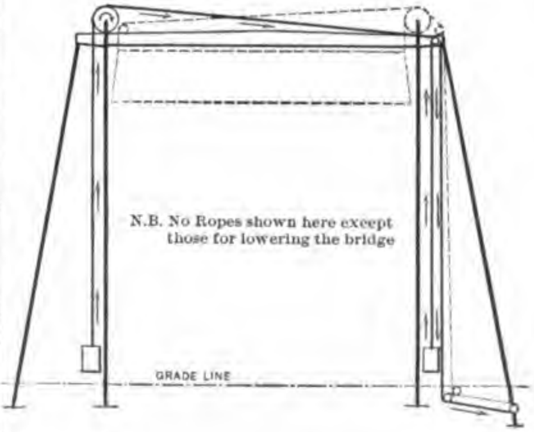
FIG. I.

PLATE III.
TRANS. AM. SOC. CIV. ENGRS.
VOL. XXXIII, No. 742.
WADDELL ON HALSTED STREET LIFT-BRIDGE.




N.B. No Ropes shown here except those for lifting the bridge

DIAGRAMS OF OPERATING ROPES.


N.B. No Ropes shown here except those for lowering the bridge

But in case there is ever any tower adjustment required, it will be found that the extra money they cost will have been well expended.

Some persons have questioned the ability of these screws to work after they have stood for some length of time; but as the rear columns carry only a small portion of the weight of the tower and occasionally some wind pressure, no great difficulty is anticipated in making adjustments, should any ever be required.

Moreover, as the main piers rest on bed-rock, while the rear piers are on grillages and piles, it stands to reason that any deviation from adjustment would be due to a settlement of the rear piers and a consequent loosening of the rear pedestals, which would relieve the load on the screws, and thus reduce the frictional resistance to turning. Provision is to be made for oiling the screws, by drilling holes into the castings and attaching oil cups thereto. This matter was overlooked in making the design. In case the main piers had not gone down to rock, the omission might have given trouble; but, as it is, it could not have done so.

Each tower consists of two vertical legs against which the roller guides on the trusses bear, and two inclined rear legs. These legs are thoroughly braced together on all four faces of the tower; and at each tier there is a system of horizontal sway bracing, which will prevent most effectively every tendency to distort the tower by torsion.

At the tops of the towers there are four hydraulic buffers that are capable of bringing the span to rest without jar from its greatest velocity, which was assumed to be 4 ft. per second; and there are four more of these buffers attached beneath the span, one at each corner, to serve the same purpose.

The span, with all that it carries, weighs about 290 tons, and the counterweights weigh, as nearly as may be, the same. As the cables and their counterbalancing chains weigh fully 20 tons, the total weight of the moving mass is almost exactly 600 tons.

Should the span and counterweights become out of balance on account of a greater or less amount of moisture, snow, dirt, etc., in and on the pavement and sidewalks, it can be adjusted by letting water into and out of ballast tanks located beneath the floor; and should this adjustment be insufficient, provision is made for adding small weights to the counterweights, or for placing such weights on the span.

As the counterweights thus balance the weight of the span, all the work which the machinery has to do is to overcome the friction, bend the wire ropes, and raise or lower any small unbalanced load that there may be. It has been designed, however, to lift a considerable load of passengers in case of necessity, although the structure is not intended for this purpose, and should never be so used to any great extent.

The span is steadied while in motion by rollers at the tops and bottoms of the trusses, as shown on Plate II. There are both transverse and longitudinal rollers, the former not touching the columns, unless there is sufficient wind pressure to bring them to a bearing. The longitudinal rollers, though, are attached to springs, which press them against the columns at all times, and take up the expansion and contraction of the trusses. With the rollers removed, the bridge swings free of the columns; and, since the attachments are purposely made weak, the result of a vessel's striking the bridge with its hull will be to tear them away and swing the span to one side. Should the rigging of the vessel, however, strike the span, the effect will be simply to break off the masts without injury to the bridge. This latter accident has happened once already, the result being exactly what the writer had predicted. There is a special apparatus, consisting of a heavy square timber set on edge, trimmed on the rear to fit into a steel channel which is riveted to the cantilever brackets of the sidewalk, and faced with a 6 x 6 in. heavy angle iron, to act as a cutting edge. This detail, which is a very effective one for destroying the masts and rigging of colliding vessels, is shown in the photograph of the structure reproduced on Plate II. The adoption of a wooden handrail on the span, while a steel one is used on the rest of the bridge, is a wise precaution against expense caused by collisions. The wooden rail is easily replaced by any carpenter, and is quite cheap; while the steel rail, if broken or bent, as it is liable to be, would be not only costly but also difficult to match in replacing, and comparatively expensive to repair. Of course, the wooden rail is not quite so sightly as the metal one. The writer had contemplated using the latter over the entire structure, and conceded the change to a wooden rail with some reluctance, but is now convinced that it is the proper thing for the place. This wooden rail and the exterior guard are standard devices of the City Engineer's office of Chicago.

The bridge is designed to carry a double-track street railway, vehicles, and foot passengers, as can be seen by the photographic view shown on Plate II. It has a clear roadway of 34 ft. between the counterweight guides in the towers, the narrowest part of the structure, and two cantilevered sidewalks, each 7 ft. in the clear, the distance between central planes of trusses being 40 ft., and the extreme width of suspended span 57 ft., except at the end panels, where it is increased gradually to 63 ft. The roadway, as shown in Fig. 2, is covered with a wooden block pavement 34 ft. wide between guard rails resting on a 4-in. pine floor that in turn is supported by wooden shims, which are bolted to 15-in. I-beam stringers spaced about 3 ft. 3 in. from center to center. These stringers are riveted to the webs of the floor beams; and beneath them run diagonal angles, which are riveted to the bottom flange of each

PLATE IV.
TRANS. AM. SOC. CIV. ENGRS.
VOL. XXXIII, No. 742.
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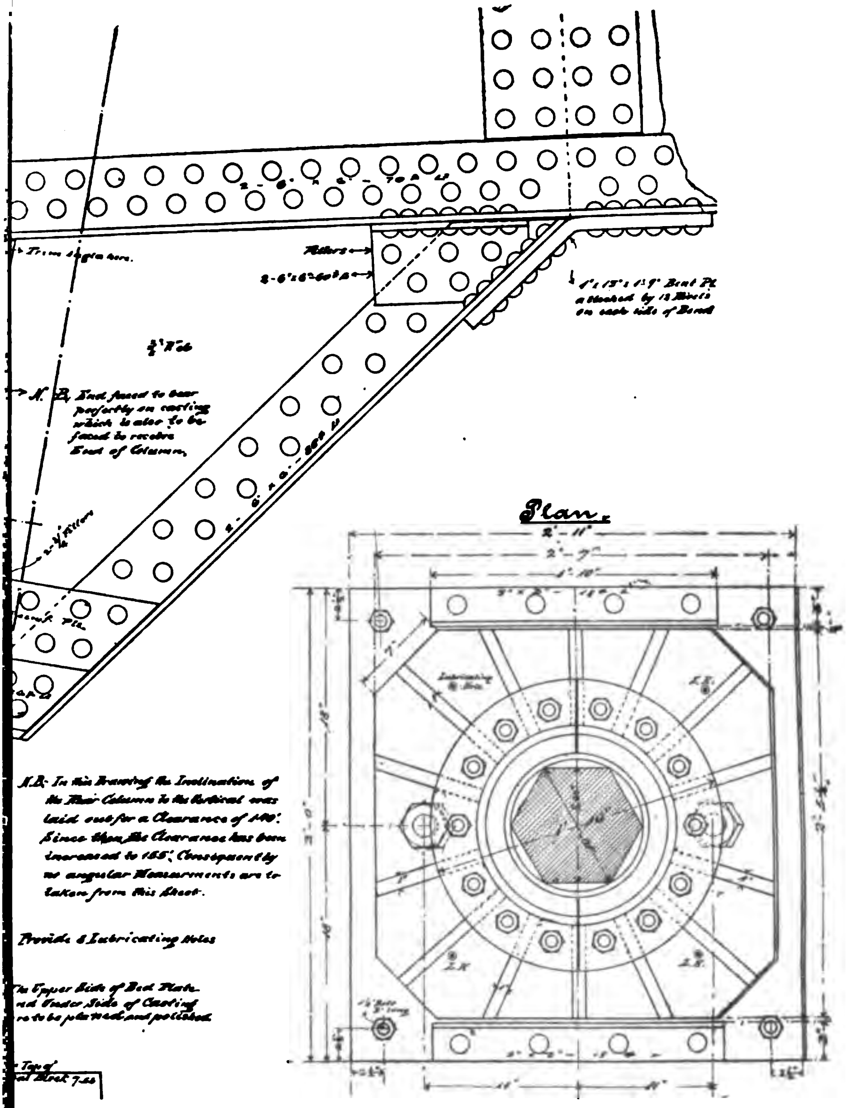


stringer, and thus form a very efficient lower lateral system. The sidewalks are covered with 2-in. pine planks, resting on 3 x 12-in. pine joists spaced about 2 ft. from center to center

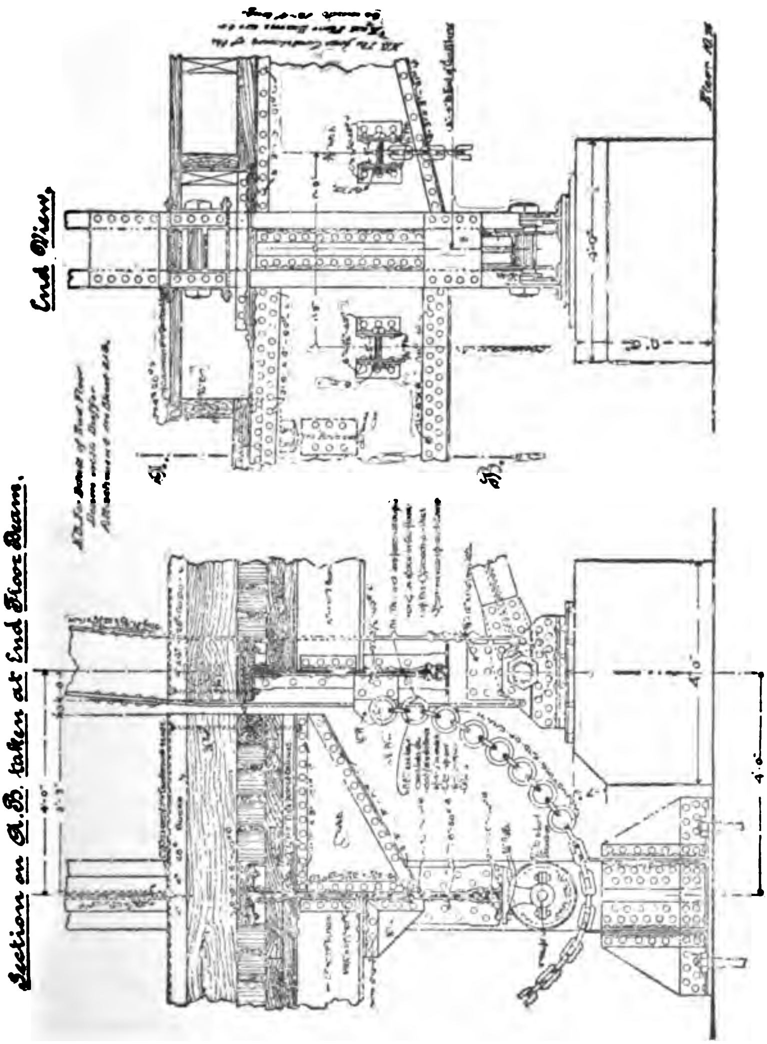


FIG. 2.

The span is suspended at each of the four upper corners of the trusses by eight steel cables which take hold of a pin by means of cast-steel clamps. This pin passes through two hanger plates which project above the truss and are riveted very effectively to the end post by means of the portal plate-girder strut on the inside and a special, short cantilever girder on the outside as shown in Fig. 1.

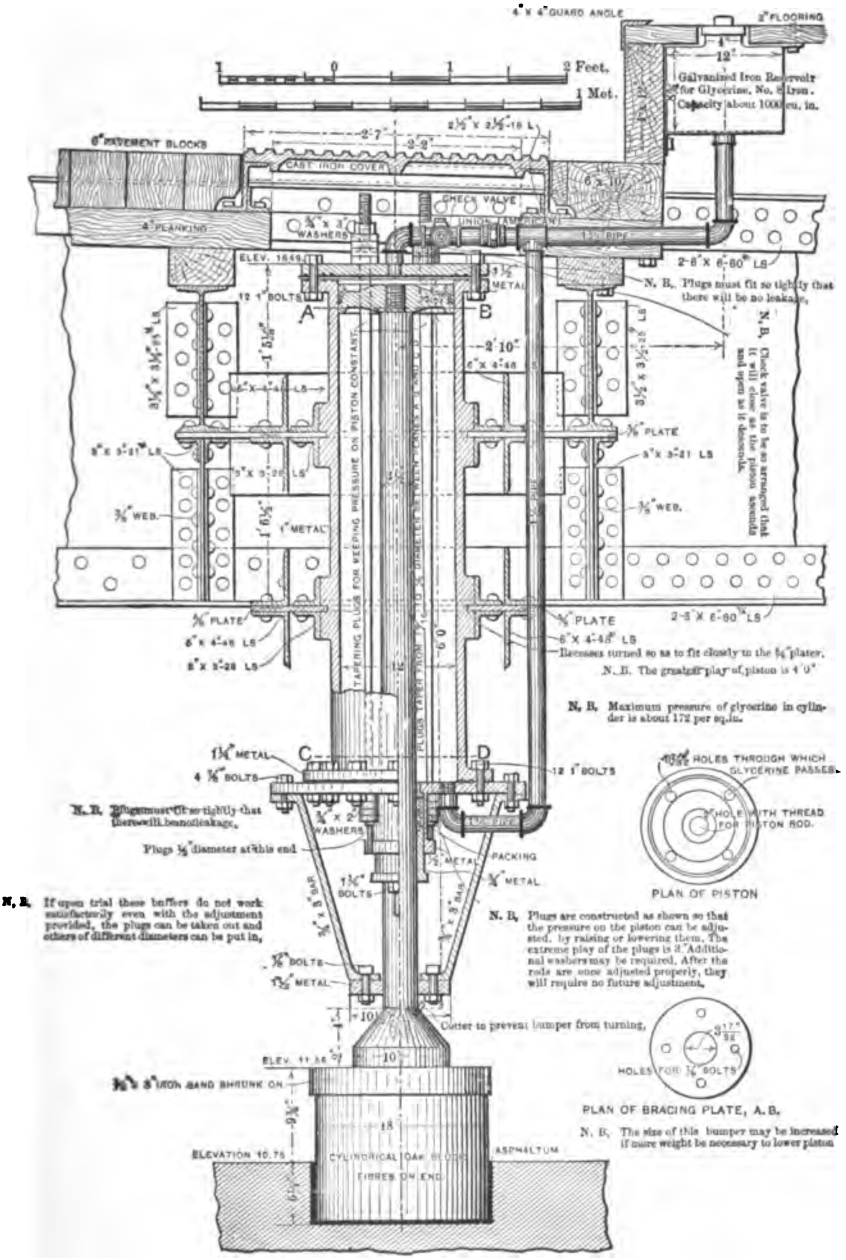
Each portal girder carries near each end an iron-bound oak block to take up the blow from the hydraulic buffer, which hangs from the overhead girder between towers. Similar oak blocks are let into and project from the copings of the main piers, as shown in Fig. 3, to take up the blow from the hydraulic buffers that are attached to the span.

The ballast tanks before alluded to, of which there are four in all, are built of steel plates properly stiffened, and have a capacity of about 19 000 lbs., which is probably more than enough to set the bridge in motion if it were all an unbalanced load. These tanks serve a double purpose, the first being simply to balance the bridge when it gets out of adjustment because of the varying load of moisture, etc., on the span, and the second being to provide a quick and efficient means of raising and lowering the span in case of a total breakdown of the machinery. If, for instance, which is highly improbable, the operating ropes were broken and had to be detached from their drums, by emptying all of the water out of the tanks the span could be made to rise. It could be lowered again by filling them from a reservoir which is placed on top of one of the towers and kept filled with water at all times by means of a pump in the machinery house. The water in all of these tanks can be kept from freezing, or the ice therein can be thawed at any time by turning on steam from the machinery room into the coils of pipe which they contain.

The necessity for using the tanks for operating the bridge will probably never arise; nevertheless, some experiments ought to be made, to ascertain what weight of water is required to unbalance the bridge sufficiently to put it in motion. In operating the bridge by the water ballast it would be necessary to take the precaution to place a simple, temporary friction brake of some kind at each corner of the span to press against the column, and thus prevent the attainment of too great a velocity. A stick of timber could be made to answer this purpose. It would do as well to apply these brakes to the main sheaves. All four tanks are connected by pipes so that the water in them can be kept at the same level; and these pipes are provided with stop-cocks so that they can be drained in winter, to prevent their contents from freezing and bursting them, or so that any one tank can be emptied without discharging the others. Should the water in the tanks freeze, it would do no harm, because the sides thereof are battered. Access is had to the tanks by means of manholes through the paved floor. These holes are covered with cast iron plates which are properly ribbed to give good foothold for horses.

On the floor at the entrances to the towers and at the corners of the

SECTION AND PART ELEVATION OF BUFFER.



N. B. Plugs must fit so tightly that there will be no leakage.

N. B. Check valve is to be so arranged that it will close as the piston ascends and open as it descends.

N. B. The greatest play of piston is 4' 0"

N. B. Maximum pressure of glycerine in cylinder is about 172 per sq. in.

N. B. Plugs must fit so tightly that there will be no leakage.

Plugs ½" diameter at this end

N. B. If upon trial these buffers do not work satisfactorily even with the adjustment provided, the plugs can be taken out and others of different diameters can be put in.

N. B. Plugs are constructed as shown so that the pressure on the piston can be adjusted, by raising or lowering them. The extreme play of the plugs is 3." Additional washers may be required. After the rods are once adjusted properly, they will require no future adjustment.

N. B. The size of this bumper may be increased if more weight be necessary to lower piston

FIG. 3.

counterweight guides curved cast iron bumpers are placed to protect the rear columns and the guides from being injured by passing vehicles.

The lower ends of the counterweight frames are fenced in with wire netting to prevent persons from injury by the descending counterweights.

It would be well to adopt automatic gates at each end of the bridge to shut off traffic from both roadway and footwalks when the bridge is being operated or just about to be. As such devices are not employed on the other Chicago bridges, at least not to any great extent, the writer did not provide for them in his design, preferring to leave the matter to the City Engineer's office. At present traffic is stopped by a policeman who stretches a rope across the roadway in the north tower; but there is nothing to prevent foot passengers from crowding out to the open ends of the footwalks, where there is the double danger of falling into the river and being struck by the descending span, in case one should let his head project over the open end of the walk.

As shown on Plate I. the main sheaves at tops of towers are covered by small houses built in a somewhat decorative style, and finished with flag-poles. The operating house on top of the span, shown on Plate II., is also slightly decorated. It is 10 ft. square on the inside, and is surrounded by a foot-walk and a suitable hand railing. When the span rises to its full height, this house passes through an opening in the bracing of the overhead struts that extend from tower to tower. The operating house contains only the signaling apparatus and the peeper, therefore it affords plenty of room for the operator or watchman. It has windows all around, so as to permit him to see in every direction.

The peeper referred to is an apparatus to enable the operator to determine when the span has risen high enough to clear the masts of an approaching vessel. As the device is covered by a patent, the contract for designing and building it was let for a fixed sum to the patentee, who has failed thus far to provide lenses of sufficient power; consequently his work has not been accepted, and will not be, probably, until he makes the apparatus work satisfactorily. Meanwhile the operator, as a matter of precaution, has to raise the span at every passage somewhat higher than he would raise it, were the peeper in operation. This is no hardship, though, because the span is raised and lowered very quickly. The best time made thus far for raising through the entire height is 34 seconds, which gives a velocity a little in excess of 4 ft. per second, the speed for which the buffers were designed.

The operating machinery is located in a room 37 x 53 ft., the opposite sides being parallel, but the adjacent sides being oblique to each other, the obliquity amounting to about 12°. The placing of this machinery beneath the street was really forced upon the writer, who had originally contemplated using electrical machinery and putting it in a house in one of the towers. As the engineer for the machinery contractor insisted upon using steam machinery, the writer deemed it unsafe to place it in the tower, owing to the injurious vibrations which might be set up; hence the expensive and rather unsatisfactory construction adopted for the house, which rests upon a timber grillage supported on piles and carrying 4 ft. of concrete as a floor. As the level of this floor is about midway between high and low water, the reason for using so much concrete becomes apparent when one considers the buoyant effort which the water is capable of exerting. Although the writer insisted that the side walls of the room should be caulked and made water-tight, this has not yet been done; hence if the machinery house be flooded, the writer must not be blamed. The timber grillage is drift-bolted to the piles by bolts which were put down through gas pipes driven into the top timbers to serve as small coffer-dams, and thus prevent the water from rising into the concrete. These pipes do not extend up to the surface of the floor, so when the latter was finished off they were filled with grouting.

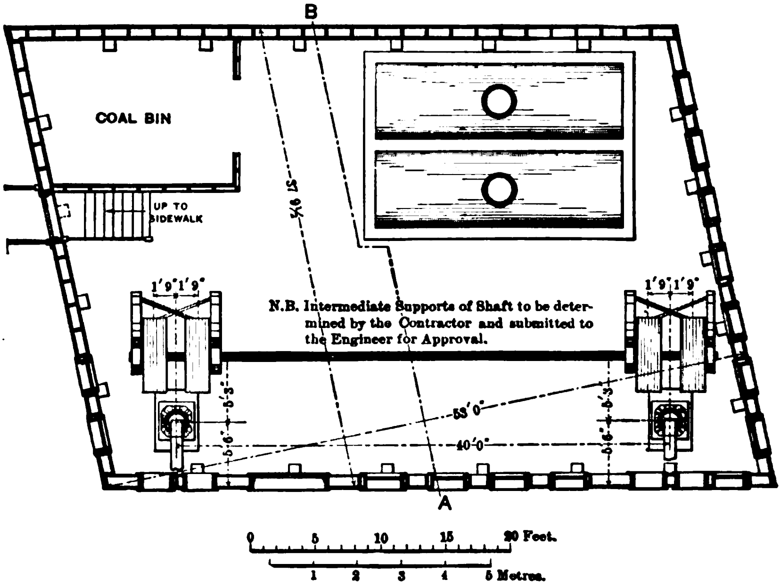
The retaining walls are built of monolithic concrete resting on a timber grillage supported on piles, as in the case of the machinery house. These walls are tied back by heavy, adjustable wrought-iron rods passing through dead-men placed some 40 ft. in the rear of the face of the wall. This construction was rendered necessary by the tendency of all retaining walls along the Chicago River to pitch forward and crack. There is a clear space of 1 ft. between the rear outer face of the machinery house and the front face of the retaining wall, so that in case of the wall slipping forward a trifle, in spite of all precautions, the machinery house will not be disturbed.

At the north end of the bridge the rear columns of the towers rest on the floor of the machinery house, but at the south end they rest on solitary masonry piers, 8 ft. square under coping and battered on all four faces. The masonry of each of these piers rests upon a timber grillage which is supported by 16 piles driven to bed-rock.

Two of the main piers as originally designed were to be of masonry and to rest on timber grillages supported on piles driven to the bed-rock, which was supposed to be 38 ft. below the city datum and overlaid with a stiff clay that was capable of holding the piles in position. Although the writer asked on several occasions that borings be made to determine the exact depth of bed-rock and the character of the overlying material, his request was refused. Afterward, under a new administration, when borings were made they showed that the rock lies some 9 or 10 ft. nearer the surface and that the overlying material consists principally of a semi-liquid clay which is incapable of retaining piles in place laterally. It is undoubtedly this condition of affairs which causes many of the river retaining walls to pitch forward and crack.

After considerable discussion the writer gained his point and changed the style of the main piers fundamentally by substituting for each of them two solitary masonry piers, 12½ x 13 ft. under coping, with battered sides, resting on a timber and concrete caisson sunk by the pneumatic process to bed-rock. Naturally, these pneumatic piers were somewhat more expensive than they would have been had they been let with the rest of the work in competition. However, when everything is duly considered, the contractor was not greatly overpaid for this portion of the work.

PLAN OF ENGINE ROOM.



N.B. Intermediate Supports of Shaft to be determined by the Contractor and submitted to the Engineer for Approval.

FIG. 4.

The stone used for the piers is Cleveland sandstone, which, although not quite as good as the Kettle River sandstone called for in the specifications, is a very satisfactory material, as has been proved by its actual use in Chicago during many years.

The arrangement of the operating machinery is shown on Plate III. and Fig. 4.

Two 70 H. P. steam engines communicate power to an 8-in. horizontal shaft, carrying two 6-ft. spiral grooved cast-iron drums, around which the ⅞-in. steel wire operating cables pass. As one of the lifting ropes passes off the drum, the corresponding lowering rope takes its place, and, *vice versa,* the extreme horizontal travel being a little less than 12 ins. Thus by turning the drums in one direction the span is raised, and by turning them in the other direction the counterweights are raised, and the span consequently is lowered. When the span is at its lowest position the full power of one engine can be turned on to pull up on the counterweights and thus throw some dead load on the pedestals of the span, after which the drums can be locked. Before the bridge was completed the writer considered that this operation would be necessary in order to check vibration from rapidly passing vehicles; but such has not proved to be the case, for the span is very rigid, and the amount of the vibration is not worth mentioning. It is possible, though, that in some other lift-bridges, where the ratio of live load to dead load is greater, this feature of operation cannot be ignored.

The engines are provided with friction brakes that are always in action, except when the throttle is opened to move the span; consequently no unexpected movement of the bridge is possible.

The stretch of the operating cables is taken up, as shown in Fig. 1, by turn-buckles near the points of attachment of the rope to the span and the counterweights; and when the adjustment is exhausted, the rope can be shortened by loosening the turn-buckle to its greatest limit and either cutting off the outer end of the rope and making a new splice, or by overhauling it on the drum and pulling the end through a hole in the periphery, placed there to afford a fastening. Each of the operating ropes stretched about 2 ft. soon after the bridge was first operated, but since then the stretch has been very slight.

As shown on Plate III., the raising ropes, after leaving the drums, pass out of the machinery house to and beneath some 5-ft. idlers under the towers, thence up to the top of the north tower where they pass over some 4-ft. idlers and the main 12-ft. sheaves. Four of them here pass down to the north end of the span and the other four run across to the other tower over more idlers, then down to the south end of the span.

The lowering ropes, after leaving the drums in the machinery room, pass under some idlers below the north tower, and thence up to more idlers at the top of the tower. Four of them here pass down to the counterweights in the north tower, and the other four run across, over intermediate idlers in the overhead bracing, to the main 12-ft. sheaves of the south tower, then downward to the counterweights.

In addition to the previously mentioned method of moving the span by the water ballast, there is a man-power operating apparatus of simple design in the machinery house which makes it possible to raise and lower the span in case the steam-power gives out, slowly when used alone or more rapidly when used in conjunction with the water ballast.

The original design contemplated operating the engines directly from the operating house on the span by ropes and pulleys, as in the case of ordinary elevators; but, at a conference with the engineers for the contractors, the writer and the City's Inspector of Machinery, Mr. F. Sargent, upon their advice, decided to operate them by signals given in the operating house, transmitted to the machinery room, and, as a matter of precaution, repeated to the operating house. The writer has thus far seen no reason to regret the decision in respect to this change of design.

As the span nears its highest and lowest positions, an automatic cut-off apparatus in the machinery room shuts off the steam from the cylinders and thus prevents the hydraulic buffers from being overtaxed.

The writer expects that Mr. T. W. Heermans will discuss this paper and will give a full description of the steam machinery and signal apparatus, and will present to the Society some indicator diagrams from which can be computed the actual power required to raise and lower the span under various conditions.

SPECIFICATIONS THAT GOVERNED THE DESIGNING.

The following is a concise statement of the leading features of the specifications, which the writer adopted when making the design:

Live load for stringers, 11 tons on a single roller 6 ft. wide.

Live load for remainder of floor system, 100 lbs. per square foot.

Live load for trusses, 4 500 lbs. per lineal foot.

Dead load for trusses, 4 100 lbs. per lineal foot.

Wind pressure for span and towers, 30 lbs. per square foot of exposed surface, including both sides of the bridge.

Intensities of working tensile stresses.

Chord bars, 15 000 lbs.
Main diagonals, from 12 500 to 15 000 lbs.
Counters (adjustable, iron), 10 000 lbs.
Lateral rods (abjustable, iron), 15 000 lbs.
Sway bracing (steel sections), 15 000 lbs.
Flanges of rolled beams (extreme fiber), 12 500 lbs.
Flanges of built beams (web resistance ignored), 15 000 lbs.

Intensities for compression members by the following formulas:

For Truss Members:

Flat ends .... $p = 15\,000 - 56\frac{l}{r}$

One flat and one pin end............ $p = 15\,000 - 66\frac{l}{r}$

Pin ends .... $p = 15\,000 - 75\frac{l}{r}$

For Sway Bracing:

Flat ends .... $p = 17\,000 - 65\frac{l}{r}$

For Pins and Rivets:

Shearing	10 000 lbs. per square inch.
Bearing	16 000 " " "
Bending	20 000 " " "

Bearing on Masonry:

Sandstone (extra strong quality),	300 lbs. per square inch.
Concrete (Portland cement)	150 " " "

N. B.—These intensities are for a combination of all loads, including wind pressure.

Pressure on Journals:

Upon projection of semi-intrados, 600 lbs. per square inch.

Pressure in Buffers:

Approximately	200 lbs. per square inch.

Tension on Wire Ropes:

Total load for 1½-in. cable	18 750 lbs.

N. B.—This corresponds (by experiment) to an initial factor of safety of about nine and one-third.

Pressure for Screw Threads of Rear Column Pedestals:

Approximately	600 lbs. per square inch.

Shafting:

Intensity on extreme fiber for combined twisting and bending	10 000 lbs. per square inch.

Minimum Thickness of Metal:

Below roadway	$\frac{3}{8}$ in.
Above roadway	$\frac{5}{16}$ "

Velocity:

Greatest velocity of span	4 ft. per second.

It will be noticed that the assumed dead load makes the span weigh only 533 000 lbs., while the actual weight is about 580 000 lbs. Of the latter amount, however, some 50 000 lbs. are concentrated either at or very near the ends of span (for instance, the weight of the hydraulic buffers, water tanks and their ballast, end floor beams, portal girders, rollers, etc.), and do not affect materially the stresses in the trusses; consequently the assumed dead load is about right.

EXTRACTS FROM THE GENERAL SPECIFICATIONS.

The following extracts from the general specifications upon which the contract for building was let will give a correct impression as to the quality of the materials in the structure and the manner in which it was built. The extracts will be taken in the regular order in which the various items mentioned appear in the original specifications, and will be condensed to the greatest extent that is compatible with a clear understanding of them. In fact, in some places, instead of making extracts the writer will simply describe tersely certain portions of the specifications, especially those which are standard.

Piles.—Straight, live, white oak timber, free from cracks, shakes, rotten knots and all defects; not less than 10 ins. in diameter at tip, nor less than 16 in. at butt.

Timber in Foundations.—Yellow pine, 12 x 12 ins., drift-bolted by ⅞-in. round bolts 22 ins. long, spaced not to exceed 3 ft., and driven into ¾-in. holes.

Masonry.—Regular coursed ashlar of the best description. Stone to be of the best quality of Kettle River sandstone, quarried near Sandstone, Pine County, Minn., or other stone equally good.

Backing.—Backing of piers to be of Portland cement concrete. Mortar for same to be mixed in the proportion by volume of 1 part cement to 2½ parts sand. To this is to be added as much broken stone as the mortar will thoroughly cover without leaving any voids in the mass.

Cement.—Best quality of English or German Portland, 90% fine, with 2 500-mesh sieve. Tensile strength of neat cement 100 to 140 lbs. at one day, and 250 to 500 lbs. at seven days.

Metal Work.—All metal in span and towers to be medium steel, excepting adjustable members, which are to be of wrought iron; rivets, which are to be of soft steel, and portions of the moving parts, which are to be of cast iron. All wrought iron to comply with the Manufacturers' Standard Specifications. Cast iron to be of tough, gray iron, free from injurious cold shuts or blow holes, true to pattern, and of a workmanlike finish. Sample pieces, 1 in. square and 4 ft. 6 ins. long between bearings to carry a central load of 500 lbs. All steel to be manufactured by the open hearth or Bessemer process. Ultimate strength of medium steel from 60 000 to 68 000 lbs. per square inch. That of rivet steel from 53 000 to 61 000 lbs.

Tests to be made according to the usual practice.

Workmanship first class in every particular.

One coat of lead paint in shop, and two coats in the field.

Workmanship on the large wheels, their axles and bearings, to be of the very best that is given in machine shops to that class of work.

Timber in superstructure to be of the best quality of white or yellow pine. Floor planks to be sized to a uniform thickness. Pavement to be cedar block and built in strict accordance with the standard specifications of the City of Chicago.

Machinery.—The entire machinery is to be bid upon in a lump sum, and is to include the following:

1. All of the machinery (of whatever kind that may be adopted) located in the machinery house beneath the street.
2. Apparatus for operating bridge by man-power, in case of breakdown of machinery.
3. All operating ropes from machinery to bridge, with their adjusting details.
4. All apparatus in operating house and that leading from same to machinery in machinery house.
5. Ropes sustaining span, together with all details attached thereto and pertaining to same.
6. Rockers between ropes and counterweights.
7. Counterweights.
8. Counterweight rods with their details.
9. Straps for keeping the component parts of the counterweights in position and letting the adjacent tiers of castings slide by each other.
10. Cast iron weights either to rest on ends of span or to be attached to counterweights, so as to adjust the balancing of weight of bridge.
11. Counterbalancing chains, with their attachments to bridge and to counterweights.
12. All guide wheels on span, together with their bearings and the details by which they attach to the chords.
13. Four hydraulic buffers at top of tower and four at bottom of span.
14. Glycerine tanks and their connections to the hydraulic buffers.
15. Glycerine for filling buffers.
16. The peeper, complete, with all its attachments to structure.
17. All signals and electric alarm bells.
18. All apparatus or machinery not herein specified that may hereafter prove necessary to operate the bridge properly and satisfactorily.

Machinery in Machinery House.—Each bidder will be required to furnish with his bid an outline plan and complete typewritten description of the machinery which he proposes using. There will be no restriction as to the kind of machinery to be used, whether steam, hydraulic or electrical, but in any case it is to be first class in every particular and acceptable to the engineer. Its capacity must be such that under the most unfavorable conditions of wind pressure, unbalanced weight, etc., it will be capable of lifting the bridge to a clear height of 100 ft. above the water in 50 seconds by using one engine only, the other engine acting as a reserve in case of breakdown. The second engine must, however, be capable of being thrown into action instantly, so that the bridge can be moved rapidly out of the way in case of the too close approach of a vessel.

All parts of this machinery must have ample strength, so as to avoid all possibility of a breakdown, more especially in those parts which are not duplicated, such as winding drums, with their shafts and gearing.

Man-Power Hoisting Apparatus.—Each bidder will be required to furnish an outline plan and complete typewritten description of this apparatus. It must be so designed as to be capable of hoisting the bridge slowly out of the way of vessels in case of any serious breakdown in the machinery, and must have sufficient strength and be of simple and easy application.

Operating Ropes.—There are to be eight of these for raising, and eight for lowering, the bridge. They are to be of 7/8-in. "Hercules" rope as manufactured by the A. Leschen & Sons Rope Company, of St. Louis, Mo., or other rope of the same diameter, and equal strength, quality, and pliability.

The adjustments of these ropes are to be made by means of long-threaded rods of sufficient strength, and the connecting details are to be of the most approved design.

Sheaves or Idlers.—These are to be about 5 ft. in diameter, of cast iron, each cast in one piece. The workmanship thereon is to be first class.

Operating Apparatus.—Each bidder will be required to furnish with his bid an outline plan and complete typewritten description of this apparatus, which must be made perfectly effective in every particular, amply strong, quick in action, and to the approval of the engineer.

Sustaining Ropes.—These are to be 1½ ins. in diameter, and of the same kind and quality as specified for the operating ropes. There are to be 32 of these ropes, eight at each corner of the bridge. All connecting details for these ropes are to be of the best standards in use.

Rockers.—Rockers between ropes and counterweights are to be built of steel in strict accordance with the requirements of the specifications for metal work.

Counterweights.—These are to be cast as smooth and true as practicable for ordinary castings, so that they will work smoothly up and down in the guides, and so that the adjacent tiers of castings can pass each other vertically without undue friction.

Counterweight Rods.—These are to be of wrought iron, of the quality specified for the metal work, upset, and furnished with nuts and washers of standard type.

Sliding Straps.—These straps, which serve to keep the counterweights in position, are to be of wrought iron, and are to be made as shown on the drawings.

Counterbalancing Chains.—These are to be of wrought iron, the weight per vertical foot of all chains being just equal to the weight per foot of the 32 supporting ropes. They are to be attached to the counterweights so as to distribute their weight equally over the supporting ropes.

Guide Wheels.—All guide wheels between span and tower are to be made of the pattern shown. They are to be of the best workmanship, so as to reduce the rolling friction to a minimum. The springs employed are to be manufactured according to the directions of the engineer.

Hydraulic Buffers.—These shall have sufficient capacity to bring the bridge to rest without shock from a velocity of 4 ft. per second, which is to be the greatest velocity allowed by the governors that are to be attached to the machinery in the machinery house. These buffers are to be of the most approved type, and of ample strength.

Glycerine Tanks.—These, with their connections to buffers, are to be of the best quality and ample strength.

Glycerine.—Glycerine for filling buffers is to be of the best quality used for such purpose; and as much of it shall be used as the engineer may deem necessary.

Peeper.—The peeper and all its connections shall be built to the satisfaction of the engineer; and the contractor shall pay any royalty that may be required by the holder of the patent for this apparatus.

Signals, etc.—Signals for warning passengers and for communicating with vessels, such as used on other bridges over the Chicago River, shall be furnished and put in place by the contractor, including two electric alarm bells of size and capacity to be determined by the engineer.

The span shall be erected on pontoons and shall be floated into position, but not until the machinery is all ready to connect to the bridge; and the obstruction to navigation, caused by putting the span into position, shall be reduced to a minimum.

Description of Details.

Span Details.—As can be seen on Plate II., the style of span does not differ essentially from the ordinary, although it has several rather uncommon features, such, for instance, as the slight inclination to the vertical of the end post, as previously mentioned, the carrying of the posts below the bottom chord pins so as to have the floor beams below the chords, and the division of the upper lateral system by a continuous longitudinal strut lying in the central plane of structure. This last detail was rendered necessary by the great distance between central planes of trusses. The dropping of the floor below the bottom chords is required by the condition of making the distance from its surface to lowest part of span a minimum. An inspection of Fig. 2 shows that the floor beams are altogether too shallow for economy of metal. The same plate shows that the paved roadway is pitched from the middle to the sides so as to draw off water rapidly.

The heavy portal girders are required for two reasons: first, rigidity; and, second, to take up the shock of the blow given to them by the buffers at the tops of the towers.

The pedestals hang from the feet of the end posts, and are pin-connected. There is a strut passing from each of the feet to the first panel point from the end. This strut would prove useful if, in winter, when there is no navigation, the suspending cables were removed in order to repair them, and the span is thus made to act like any ordinary span, changes of temperature would cause a bending on the extended portions of the end posts. The struts prevent this, and would, in such a case, cause the span to slide sufficiently to accommodate the expansion and contraction. The end posts are figured to carry both the entire dead and live loads, although under ordinary conditions the former is never carried by them, but is taken up by the suspending cables.

The top and bottom chords (the latter being stiff in the end panels) project beyond the end panel points so as to afford connection for the rollers. Behind each longitudinal roller is a spring which keeps the roller pressed at all times against the column. Should the span tend to lurch forward, there is a stopper in each spring, which prevents such lurching from exceeding a certain limit. The connections of all rollers to the span are strong enough to withstand the wind pressure and any blow from the masts or rigging of a vessel; but should the hull of the latter strike the span, these connections would fail and allow it to swing sideways, which it would do until the vessel would be brought to rest.

The connections of cantilever brackets to floor beams around the posts, as shown in Fig. 2, have been objected to as being too elaborate for the size of the cantilevers; but the writer holds that such a detail is necessary in any case, in order to avoid direct tension on rivets. The tightly fitting straining angles at the post feet are also just as necessary as the upper connection, unless some equally efficient detail, such as an underneath plate extending from cantilever to beam, be adopted.

The detail for attaching the span to the cables is shown on Plate II and Fig. 1. Some difficulty was found in designing a satisfactory and efficient connection for the ends of the sustaining ropes. The Crane Elevator Company objected to the detail first proposed by the writer on account of expense; consequently, at his request they submitted a design of their own. Upon examining it, the writer pronounced it inefficient, and proceeded to submit it to test, with the result that his judgment was verified. The company then submitted another similar, but improved, design, shown in Fig. 1, which the writer judged would be strong enough to develop the full strength of the rope. Some tests to destruction proved the correctness of this surmise; and it is the writer's opinion that this design for the clips is the best and most efficient that can be made, although it must be confessed that its appearance is somewhat clumsy. Hitherto no one appears to have used clips that would even begin to develop the full strength of wire rope; but in this case it is essential, notwithstanding the fact that it is contemplated to use these cables until they have lost as much as 40% of their strength.

Tower Details.—Each of the main columns of the towers is built of a single ½ x 20-in. plate and four 6 x 6-in. 50-lb. angles, which form a built I-beam that is riveted between two 15-in. 150-lb. channels turned face to face, the web of the built I-beam lying in a plane transverse to the length of span. The front face of this column is left open so as to permit of the travel of the vertical roller, but the back face is stay-plated occasionally. Wherever the rollers touch the column, the rivet heads are countersunk so as to be perfectly flush with the web. The column is expanded at the foot, as shown in Fig. 5, so as to give a sufficiently low bearing pressure on the masonry and to distribute it uniformly without overstraining any of the metal. The boxed spaces in the foot are filled with bituminous concrete.

At the top of the tower each column is expanded, as shown in Fig. 6, so as to afford proper support for the journal boxes of the main sheaves. These boxes are lined with bronze, which is grooved spirally so as to carry the lubricant to the bottom of the bearing and distribute it uniformly.

Attention is called to the rigid character of the sway bracing in numerous planes in the vicinity of the main sheaves. No metal was spared in the endeavor to obtain the greatest practicable rigidity.

The bracing in the plane of the main columns consists of a heavy plate-girder portal near the bottom carried down the sides of the columns to the large floor beam and connected to it, and a similar, but lighter, plate girder at the top to aid in carrying the main sheaves, and to take up the uplift from the buffers. Between these girders there is a double cancellation system of sway bracing, each diagonal and transverse member of which consists of four angles in the form of an I-beam with a laced web. This system of sway bracing has much greater strength than the computed wind stresses require, but it was put in thus for the sake of rigidity.

The single cancellation system of sway bracing between the main and the rear columns consists of struts, each built of two angles in the form of a star, and stayed to each other by short pieces of angle iron spaced about 3 feet centers; but one member in the first tier below the main sheaves is a built I-beam, designed to carry the counterweights before the span is attached to them by the sustaining cables, and the diagonal in the bottom panel is composed of four angles in the form of a star. These star struts make a good and rigid bracing; nevertheless, in a new design the writer would use more metal and adopt four Z-bars.

DETAILS OF FOOT OF MAIN COLUMN.

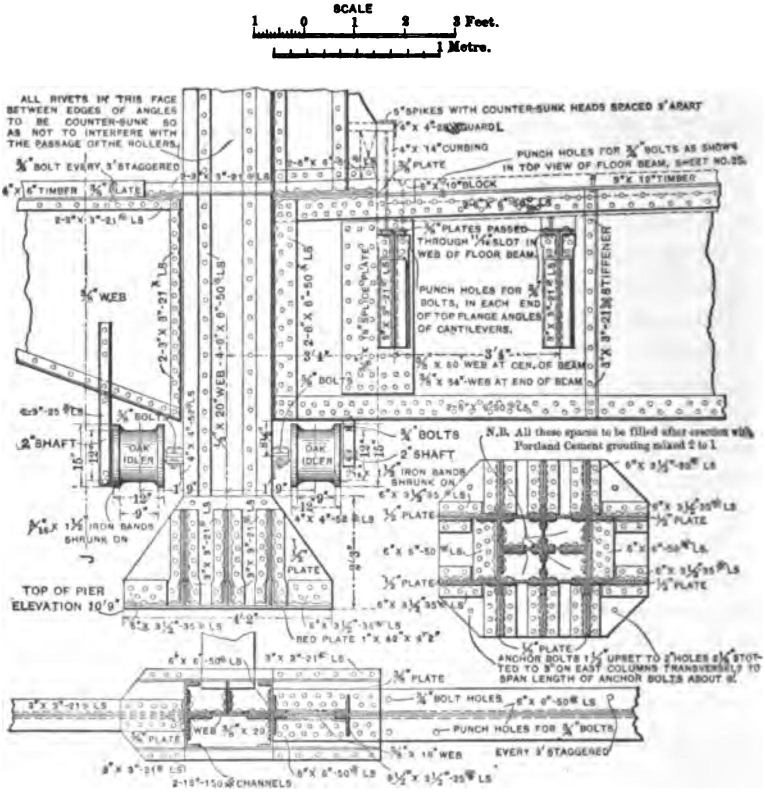
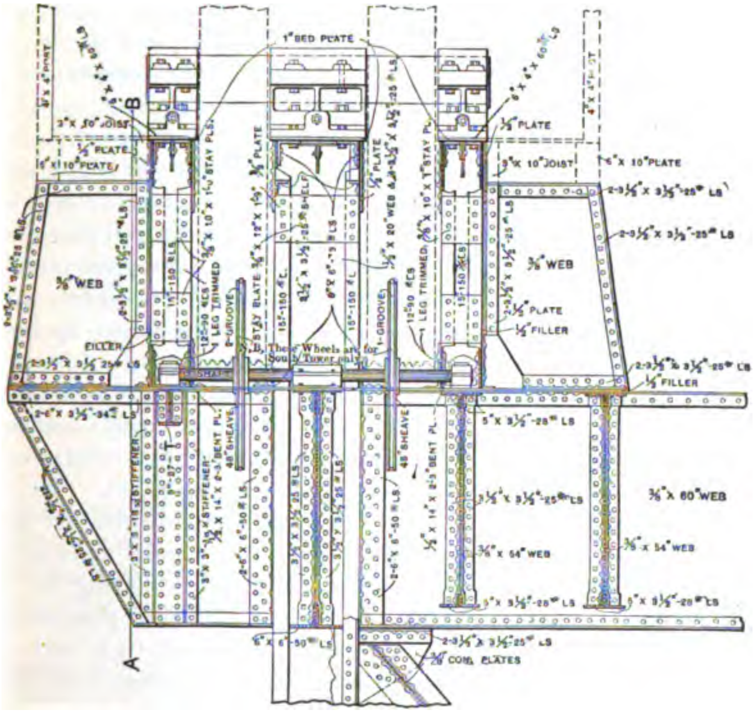


FIG. 5.

The sway bracing between the rear columns is put in for rigidity only, because its figured stresses are insignificant. The main sheaves are built up of steel plates and angles with a cast-iron periphery grooved to fit the wire ropes. This design is a modification of one made especially for the writer over two years ago by Thomas E. Brown, Jr., M. Am. Soc. C. E., who had been called in consultation when the plans for the proposed lift-bridge at Duluth were being prepared.

Overhead Bracing Details.

As shown on Plate I., the overhead bracing between towers consists of two lattice girders built of angles and having a double system of cancellation for the web, which changes, however, at the ends into plates. Between these girders there is a system of sway bracing similar to that between the top chords of the span and containing the same peculiar feature of an intermediate longitudinal strut. In this case, though, this strut, instead of being continuous from end to end, is made in two parts, and does not extend across the middle bay, which is left unbraced, so as to permit the operating house to pass through. The detail for connecting this system to the towers is very simple and effective. It was suggested by Mr. Curtis and accepted with a slight modification by the writer. Its essential feature consists in cutting the girders (as originally designed)



DETAILS AT TOP OF MAIN COLUMNS.

SCALE
1 0 1 2 3 Feet
1 Mètre.

FIG. 6.

through the plate-girder portions near the ends by planes inclined to the vertical, so as to make the length of the top chord of the intermediate portion shorter than that of the bottom chord, facing all the cut ends with stiffening angles, riveting the short pieces on to the towers, and hoisting at one operation the two intermediate pieces with all their sway bracing, which had previously been assembled and riveted together on the falsework, so that the oblique ends met; then these ends were riveted together, and the flanges of the girder were spliced above and below by cover plates.

Machinery Details.—As shown in Fig. 3, each hydraulic buffer consists of a cast-iron cylinder 12 inches internal diameter and 4 feet stroke, with a tightly fitting piston, that has through it four symmetrically disposed holes. Through each of these holes passes a tapered rod. When not in use, the head, owing to the weight of the piston, lies at the bottom of the cylinder, but, when struck, rises and forces the fluid (a light petroleum product) through the four annular spaces around the rods. As will be shown later on, the taper of the rods is so figured that the total pressure on the piston remains constant at all positions of the piston head for any one stroke. Should the calculations have been slightly at fault, the resistance of the buffer can be increased or decreased by lowering or raising slightly the rods by means of the screw adjustment provided in the design; and should this be insufficient, it would be a simple matter to take out the rods and put in new ones with a different taper. Fortunately, though, the buffers, as nearly as can be determined by a casual examination, appear to work exactly as they were designed to do. The writer had some doubt about the ability of the piston to descend of its own weight unless it were made to fit so loosely in the cylinder as to permit of the passage of some of the fluid around the periphery during the stroke, but his fears were groundless, for only one of the eight pistons showed any tendency to stick, and that one began to work all right in a day or two. The idea of running rods through the piston came from Edward Flad, M. Am. Soc. C. E. He very kindly placed his invention at the disposal of the writer, who personally made the original design, computations, and drawings for the buffers of the bridge. This design was not varied from essentially in making the working drawings.

As the piston ascends, the total amount of metal within the cylinder is constantly increased; consequently the amount of fluid therein is correspondingly diminished, the excess passing out of a pipe at the bottom and into a small reservoir situated only a few feet above. As the pressure of the escaping fluid is quite small, the reservoir is left open to the air, and there is no loss of fluid involved.

The attachment of the balancing chains to the counterweights provides for an equal distribution of the weight of the chains over all the sustaining cables, even should the latter stretch unequally.

The design for the drum, shown on Fig. 4, is very simple, and requires no further explanation.

The driving wheels are placed symmetrically near the middle of the drum shaft. They are cast-iron spur gears, 10 feet in diameter. These and all the rest of the machinery between them and the engines were designed by the Crane Elevator Company under the inspection of and to the approval of Mr. F. Sargent.

The operating ropes are attached to the span and counterweights, as shown in Fig. 1, by means of ordinary clips, such as are used in elevators. The detail for lining up and clamping the suspending ropes was manufactured and delivered on the ground, but the bridge was found to work so nicely without it that it was decided not to put it in.

Testing.—All testing was done by Messrs. G. W. G. Ferris & Co., of Pittsburg, who are the regularly employed inspectors of bridge materials for the City of Chicago. The usual tests of the steel were made, and the results were fairly good, considering that the use of Bessemer steel was permitted. Some very interesting tests of wire rope were made by these gentlemen under the direction of the writer, who hopes that some of the engineers of the firm will see fit to contribute to the discussion of this paper by giving a full description of these tests and the conclusions to be drawn therefrom in respect to the ultimate strength and other properties of steel wire ropes.

CALCULATIONS.

Buffers:

Moving weight .... = 1 200 000 lbs.
Moving mass .... = $1\,200\,000 \div 32.2 = 37\,267$.
Maximum velocity .... = 4 ft. per second.
Energy due to same .... = $37\,267 \times (4)^2 \div 2 = 298\,136$.
say—300 000 ft.-lbs.
Number of buffers .... = 4.
Energy per buffer due to moving mass .... = $300\,000 \div 4 = 75\,000$ ft.-lbs.
Stroke of buffer .... = 4 ft.
Constant pressure on piston .. = $75\,000 \div 4 = 18\,750$ lbs.
Diameter of cylinder .... = 12 ins.
Area of cylinder .... = 113 sq. ins.
Area of four holes .... = 4 sq. ins. (approximately).
Net area of piston .... = $113 - 4 = 109$ sq. ins. = A.
Intensity of pressure on piston = $18\,750 \div 109 = 172$ lbs.
Hydraulic head due to 172 lbs. pressure .... = 396 ft., say, 400 ft.
Formula for velocity through holes .... $v' + 0.7\sqrt{2gh}$.
$= 0.7 \times 8\sqrt{400} = 112$ ft. per second (nearly).

Let v = velocity of piston at any part of the stroke. Its value will diminish uniformly from 4 ft. per second to zero.

Let A' = net area of the four orifices for the position of piston corresponding to the varying velocity v.

Then by the law of continuity—

$$A v = A' v', \text{ and } A' = \frac{Av}{v'} = \frac{109}{112} v = 0.973 v.$$

$$\text{For } v = 4, A' = 3.892 \text{ sq. ins., and } \frac{A'}{4} = 0.973 \text{ sq. in.}$$

$$\text{For } v = 3, A' = 2.919 \text{ sq. ins., and } \frac{A'}{4} = 0.730 \text{ sq. in.}$$

$$\text{For } v = 2, A' = 1.946 \text{ sq. ins., and } \frac{A'}{4} = 0.486 \text{ sq. in.}$$

$$\text{For } v = 1, A' = 0.973 \text{ sq. in., and } \frac{A'}{4} = 0.243 \text{ sq. in.}$$

$$\text{For } v = 0, A' = 0.000 \text{ sq. in., and } \frac{A'}{4} = 0.000 \text{ sq. in.}$$

Let us assume diameter of plug at bottom = ½ in.

Then area of plug at bottom = 0.196 sq. in.

Therefore area of hole in piston = 0.973 + 0.196 = 1.169 sq. ins.

Diameter corresponding to 1.169 sq. ins. = $1\frac{7}{32}$ ins. (nearly).

Diameter of plug at top must be almost exactly $1\frac{7}{32}$ ins., so as to fit the hole tightly, but without binding.

For v = 3, area of plug = 1.169 — 0.730 = 0.439 sq. in., corresponding to a diameter of 0.748 in.

For v = 2, area of plug = 1.169 — 0.486 = 0.683 sq. in., corresponding to a diameter of 0.936 in.

For v = 1, area of plug = 1.169 — 0.243 = 0.926 sq. in., corresponding to a diameter of 1.086 ins.

If the plug were conical, the diameters at the several quarter points would be respectively 0.68 in., 0.86 in., and 1.04 ins., consequently it will have to be swelled a little beyond the conical surface in order to make the total pressure on the piston constant at all parts of the stroke.

These calculations were furnished by the writer to the subcontractors for the machinery. How closely they adhered to them in manufacturing the buffers he cannot say; but, at any rate, the latter work satisfactorily, which is all that is really necessary. It is seldom that the span will strike the buffers with a velocity of 4 ft. per second, for two reasons: first, it is not necessary to operate the bridge at such a velocity; and, second, the automatic cut-offs in the engine-room reduce the speed near the ends of the travel. On the other hand, though, if the span be out of balance, the buffers will have to overcome an extra amount of energy equal to the unbalanced load multiplied by the buffer stroke.

If the unbalanced load for an extreme case be assumed equal to 5 000 lbs., the total extra energy to be overcome will be 20 000 ft.-lbs., or 5 000 ft.-lbs. per buffer. This is, however, less than 7% of the capacity of the buffer.

Power.—The amount of power required is dependent mainly upon the coëfficient of friction in the journals of the main sheaves. Unfortunately, but little is known concerning its probable value for such a case as this. A study of the various authorities shows a very wide range of opinion. It is well, perhaps, to assume with Morin that its value is 0.05 for ordinary working pressures and ordinary conditions.

Let us investigate three cases, viz.:

1st. No wind acting, balanced loads, and a maximum velocity of 3 ft. per second.

2d. No wind acting, balanced loads, and a maximum velocity of 4 ft. per second.

3d. Greatest assumed wind pressure acting, an unbalanced load of 2 000 lbs., and a maximum velocity of 2 ft. per second, which velocity will probably just suffice to raise the span, according to contract, 85 ft. in 50 seconds.

CASE NO. 1.

Load on journals............ = 1 320 000 lbs.
Frictional resistance of journals = 1 320 000 x 0.05 = 66 000 lbs.
Velocity of axle in journal.... = 0.25 ft. per second.
Work of friction............ = 66 000 x 0.25 = 16 500 ft.-lbs.

$$\text{Corresponding horse-power} \ldots = \frac{16\,500}{550} = 30.$$

Inertia.—Let us assume that in 15 ft. the full velocity of 3 ft. per second will be developed.

$$\text{Mass} \ldots = \frac{1\,200\,000}{32.2} = 37\,267.$$

$$\text{Kinetic energy} \ldots = \frac{37\,267}{2} \times (3)^2 = 167\,700 \text{ ft.-lbs.}$$

The average velocity during development = 1.5 ft. per second.
Time required for development = 10 seconds.

$$\text{Energy expended per second} = \frac{167\,700}{10} = 16\,770.$$

$$\text{Corresponding horse-power} = \frac{16\,770}{550} = 30.5.$$

Bending Cables.—For a velocity of 3 ft. per second, it will take approximately 6 H. P.

Summation.—The sum of these three values is equal to 66½ H. P., nearly. This seems high, and it is more than likely that the experiments about to be made will show, first, that the coëfficient of friction is less than 0.05; and, second, that it takes ordinarily a greater travel than 15 ft. to develop a velocity of 3 ft. per second.

CASE NO. 2.

Friction.—The work of friction is directly proportional to the velocity; consequently in this case the horse-power will be $30.0 \times \frac{4}{3} = 40.0$.

Inertia.—Energy developed $= \frac{37\,267 \times (4)^2}{2} = 298\,136$ ft.-lbs.

The average velocity during development = 2.0 ft. per second; therefore, the time, as before, will be 10 seconds.

Energy per second........ $= \frac{298\,136}{10} = 29\,814$ ft.-lbs.

Corresponding horse-power $= \frac{29\,814}{550} = 54.3$.

Bending Cables.—For a velocity of 4 ft. per second, it will take approximately 8 H. P.

Summation.—The sum of these three values is equal to 102 H. P., nearly. With this arrangement of speed, the time required would be as follows:

To attain maximum velocity	10 seconds.
Duration of same = 116 ÷ 4...............	29 "
To overcome same in 4 ft.	2 "
Total	41 "

If these figures are correct the bridge must have been considerably unbalanced when it was moved the full height in 34 seconds. That it was somewhat unbalanced was known, because the span went up more quickly than it went down, although the difference of time for raising and lowering was ordinarily not very much.

CASE NO. 3.

Friction.—For a velocity of 2 ft. per second, the horse-power required will (from Case No. 2) = 40.0 ÷ 2 = 20.0.

Inertia.—The energy developed will be $\frac{298\ 136}{4} = 74\ 534$ ft.-lbs., and the time, as before, 10 seconds; therefore, the energy per second will be $\frac{74\ 534}{10} = 7\ 453$ ft.-lbs., corresponding to a horse-power of $\frac{7\ 453}{550} = 13.6$.

Bending Cables.—For a velocity of 2 ft. per second, it will take approximately 4 H. P.

Unbalanced Load.—

Energy = 2 000 x 2 = 4 000 ft.-lbs., corresponding to a horse-power of 7.3.

Wind Pressure on Span:

Total wind pressure on span = 50 000 lbs., nearly.
Diameter of roller = 15 in.
Diameter of axle = 5 in.
Velocity of axle $= \frac{5}{15} \times 2 = 0.67$ ft. per second.
Coëfficient of friction = 0.05.
Frictional resistance = 50 000 x 0.05 = 2 500 lbs.
Work of friction = 2 500 x 0.67 = 1 675 ft.-lbs.
Corresponding horse-power $= \frac{1\ 675}{550} = 3.0$, nearly.

To this should be added about 1 H. P. for the rolling friction, making the total horse-power for rollers = 4.0.

Wind Pressure on Counterweights:

Areas exposed = 4 x 8 x 10 = 320 sq. ft.
Pressure on same = 320 x 30 = 9 600 lbs., say, 10 000 lbs.
Assume coëfficient of friction = 0.15.
Frictional resistance = 10 000 x 0.15 = 1 500 lbs.
Work of friction = 1 500 x 2 = 3 000 ft.-lbs. per second.
Corresponding horse-power $= \frac{3\ 000}{550} = 5.5$, nearly.

Summation.—The sum of all these values is 54.4 H. P. From this it is evident that, if the various assumptions are correct, one 70-H. P. engine will easily raise the span 100 ft. clear above the water in 50 seconds, under a wind pressure of 30 lbs. per square foot, and with 1 ton of unbalanced load on the span; consequently the contractor has complied generously with the specifications.

Erection.—The treatment of this subject will be left to Mr. W. W. Curtis, the engineer who represented the contractors, and under whose personal supervision it was so ably done. There is but one adverse criticism to make concerning it, viz., the great length of time it took; but for this there are many extenuating circumstances. Under like conditions many a contractor would have thrown up the contract in despair; and, in the writer's opinion, if Mr. Curtis had the work to do over again, with everything favorable, instead of unfavorable, he would finish it all in the contract time. It was contemplated, when the specifications were written, to erect the span on pontoons, float it into place, and raise it clear of everything in a single day; but the erection being delayed until after the close of navigation, the contractor was permitted to drive false-work piles all the way across the river. The passage of the latter for tugs was blocked in consequence only three or four days.

Estimates.—Owing to unavoidable changes in both substructure and superstructure, it is not practicable to check the total cost of bridge with the preliminary estimate, which was based upon the quantities given at the end of the "General Specifications." There is only one item of all these that it is convenient to check, viz., the total weight of metal, 1 250 000 lbs. To this must be added the writer's preliminary estimate of 100 000 pounds for raising the towers 15 ft., making the total estimate weigh 1 350 000 lbs., which agrees within 5 000 lbs. with an estimate made in the writer's office from the complete detail drawings.

The reasons why the total cost of the bridge is higher than was anticipated are as follows:

1st. Increased cost of superstructure (nearly $5 000) because of the increased height of towers.

2d. Greater expense involved by the necessary change from pile piers to pneumatic piers.

3d. Adding to the legitimate cost of the structure that of removing the old pivot pier and doing considerable dredging for the purpose of deepening the channel.

4th. Extra expense for engineering and inspection due to the delay in completing the structure.

If the contract for building a duplicate of the Halsted Street lift-bridge were to be let to-day, at present prices, with close competition, and if the engineer were allowed full sway in making plans and specifications for substructure, superstructure, approaches, and machinery, based upon correct data, it is not too much to say that the entire cost would be reduced to, at most, $150 000, instead of $200 000, which is about what the structure itself would cost, exclusive of outside extras.

ADVANTAGES OF LIFT-BRIDGES.

The advantages of lift-bridges, in comparison with rotating draw-bridges, are as follows:

1st. A lift-bridge gives one wide channel for vessels instead of the two narrow ones afforded by a center-pivoted swing-bridge.

2d. There are no land damages in the case of a lift-bridge, as the whole structure is confined to the width of the street. These land damages in the case of some swing-bridges amount to a large percentage of the total cost of structure.

3d. Vessels can lie at the docks close to a lift-bridge, which they cannot do in the case of a swing-bridge; consequently with the former the dock front can be made available for a much greater length between streets than it can with the latter.

4th. The time of operation for a lift-bridge is about 30% less than that for a corresponding swing-bridge.

The advantages of a lift-bridge in comparison with a bascule or a jack-knife draw, both of these being supposed to be without a center pier, are as follows:

1st. The lift-bridge can be made of any desired span, while, in the case of the others, the span is necessarily quite limited in length.

2d. A lift-bridge can be paved, while the others cannot.

3d. The lift-bridge is very much more rigid than any structure composed of two or more partially or wholly independent parts, a feature characteristic of the jack-knife bridge or the bascule without a center pier.

4th. In a lift-bridge, the operating machinery is much more simple; and, in case that it should ever get out of order, the span can be raised or lowered either by unbalancing, or by simple hand mechanism, or by both combined.

Conclusion.—In concluding this paper the writer desires to give full credit to the following gentlemen:

Primarily, as before stated, to the Hon. J. Frank Aldrich is due the fact that the bridge is in existence.

To W. W. Curtis, M. Am. Soc. C. E., is due great credit, not only for the careful and conscientious manner in which all of his work was done, but also for his unfailing courage in dealing with continual occurrences of the most disheartening character.

To Mr. T. W. Heermans, engineer for the machinery contractor, is due the credit of the fact that every portion of the machinery went together as it was designed.

To S. M. Rowe, M. Am. Soc. C. E., the resident engineer, is due the credit of the correct location of all parts of substructure and superstructure.

To Mr. Ira G. Hedrick, the writer's engineer and chief draftsman, and to Mr. Rudolf Markgraf, his architect, are due the credit of preparing the complete detail drawings for the entire structure, excepting the steam machinery and signal apparatus, which were designed, as well as built, by the Crane Elevator Company.

It would be unfair to omit to mention Lee Treadwell, Assoc. M. Am. Soc. C. E., the writer's principal assistant engineer, who, although but slightly connected with the designing of the Halsted Street bridge, was, nevertheless, instrumental in evolving many of the special details employed therein, when studying with the writer on the design for the proposed lift-bridge for Duluth. Moreover, he assisted in making the drawings for the span of the Halsted Street bridge.

As before mentioned, the writer is indebted to Thomas E. Brown, Jr., M. Am. Soc. C. E., for many valuable suggestions concerning general details, and to Edward Flad, M. Am. Soc. C. E., for his kind permission to use his idea for hydraulic buffers.

The Halsted Street lift-bridge has now been in operation long enough to show that all that was claimed for it by its projectors was true, and that it works even more easily than was anticipated. The writer is now engaged on the preliminary designs for several similar structures in which the manner of operation will reduce the cost to less than that for corresponding swing-bridges; and, as the first cost of other lift-bridges can be made very much less than that of the pioneer structure, it is not improbable that in the next few years many structures of this type will be built over navigable waters in American cities adjacent to the seacoast and the Great Lakes.

DISCUSSION.

Gustav Lindenthal, M. Am. Soc. C. E.,

remarked that while the paper was very interesting, there were some parts which were omitted, for instance, the testing of the wire ropes. This question had recently come up in discussion in connection with the use of sockets for fastenings, and it was shown by tests that that method was unreliable, because it was very difficult in practice to pin every wire fast in the socket, and hence the full strength of the wire rope was never developed in testing to destruction.

The reason for the use of this type of bridge is given in full by the author, namely, that at the site of the bridge the U. S. War Department objected to the use of an ordinary draw-bridge as an obstruction to navigation, and that the type adopted was thought to be one which would meet those objections. He did not think, however, that this type of bridge would be used generally as a substitute for draw-bridges, because it was more expensive in first cost and more expensive to maintain.

L. L. Buck, M. Am. Soc. C. E.,

stated that he had not been able to give the paper the attention which he would like to do before entering into a detailed discussion of it, but that he could not at the present moment see any good reason for raising the whole span to such a height as to permit the passage of masted vessels under it. His feeling was that, had the problem been presented to him, he would have exhausted all other resources before adopting the plan of the author. He had heard that objection to a draw-bridge was made bp the War Department, but on the Erie Canal the State of New York also objects to draw-bridges. It occurred to him that raising the floor of the bridge alone might be a more desirable method. The supporting structure could then be placed above and made stationary and permanent. An examination of a draw-bridge across the Chicago River had satisfied him that a satisfactory solution of the problem might be worked out in this way.

G. H. Thomson, M. Am. Soc. C. E.,

called attention to the fact that on page 35 some of the advantages of lift-bridges are noted. One other advantage can be mentioned, viz., lift-bridges can be manipulated with ease while a stiff gale is blowing, and this has been tested with the type known as the end lift-bridge. The difficulty of manipulating circumrotary draws during gales has been experienced in both hand and power swing bridges of equal arms; while the bob-tail draw (unequal arms) presents much greater difficulties in the way of rotation.

Another advantage in some types of lift-bridges is that the amount of coal required is less than the amount required for rotary draws of equal single span.

The statement that a lift-bridge of the bascule type cannot be paved (sic) will not find acceptance with those who think that there is no difficulty in laying wooden block pavement on bridges with inclined surface roadways.

He further remarked that the cost of this structure seems excessive; that how much of this cost is chargeable to substructure does not appear, and that it would be interesting to know the weight of the towers. The paper, with its accompanying plan, does not disclose this, and an economy analysis is not easily made offhand. The magnitude of the counterweighting (given at 290 tons) is something more than an "end" lift-bridge requires. An "end" lift-bridge needs but one tower of about one-half the height, with presumably less material than the Halsted Street bridge towers.

He called attention to an end lift-bridge designed for W. Katté, M. Am. Soc. C. E. (see Plate V.), a view of which shows a double-track end lift-bridge on temporary line over the Harlem River, of a total length of 106 feet, center of end pin to extreme end. It has been lifted about 50 times a day for about six months, and one and one-half minutes is the usual time of a full lift, and it is responsive in action.

The Halsted Street bridge is rapid in movement. One double-track through plate (of 60-feet span) end lift-bridge has been lifted to the full height in nine seconds.

He thought the selection of any type of lift-bridge should be the result of mature deliberation after weighing all the conditions presented in each particular case; that some situations point to the selection of a lift-bridge as justifiable, whether viewed in the light of first cost or cost of maintenance, while others admit of no other type of draw, but that the usual conditions presented by most situations permit the use of the rotary draw, and economy and other matters indicate soundness of judgment in its adoption.

F. W. Skinner, M. Am. Soc. C. E.,

complimented the author on the excellent manner in which he had presented the paper, and called attention to the elaborate and unusual screw adjustment at the base of the towers, which he presumed had been very fully studied, but which at first glance seemed to be somewhat remarkable. As adjustments would require to be made very infrequently at most, it seemed to a casual observer as if it would have been better to simply arrange for differential loose packing plates and the temporary insertion of hydraulic jacks, than to use costly steel screw bearings.

He said further that the design of bridges that should cause the least interruption of traffic on the numerous highways and waterways of large cities is a subject that had lately received special attention by a large number of the most prominent bridge builders. Notably interesting and original designs were prepared by the late Mr. Scherzer, and the engineers associated

PLATE V.
TRANS. AM. SOC. CIVIL ENGRS.
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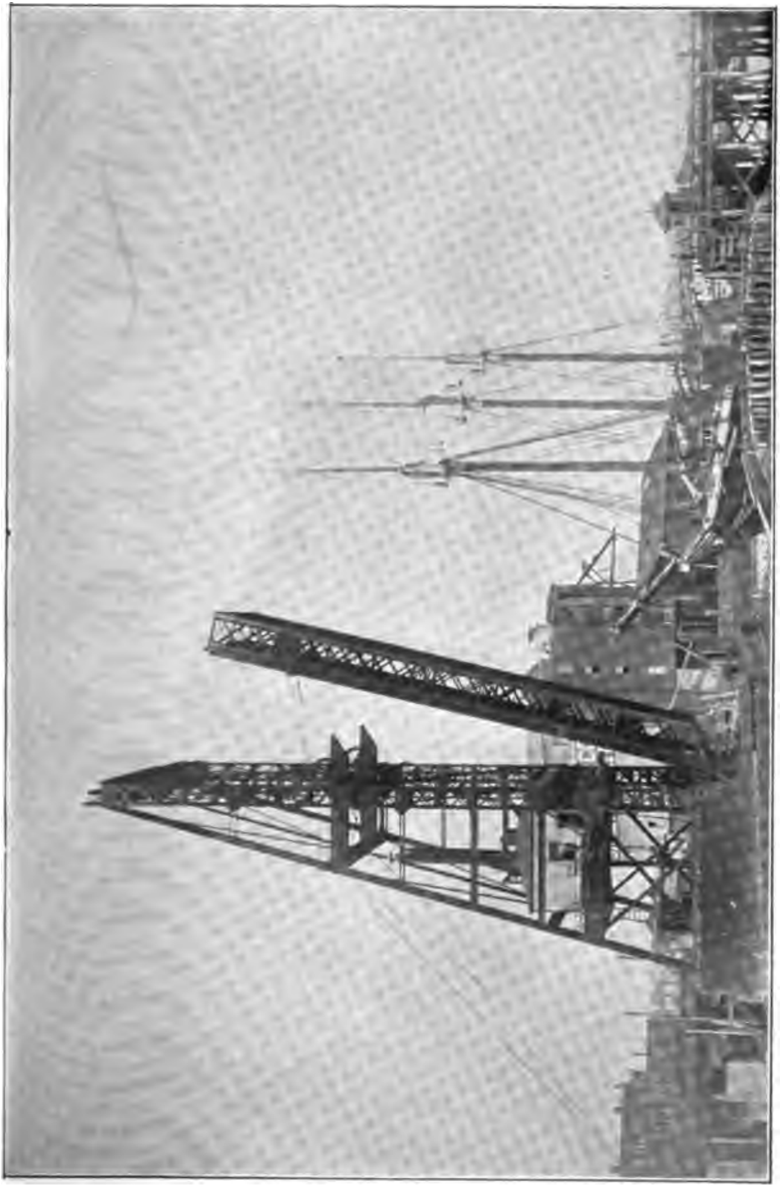
THOMSON ON HARLEM RIVER END LIFT-BRIDGE.



with the elevated road in Chicago, while the author had carefully developed a fundamentally distinct line of construction. He called attention to a type of bridge differing from that described by the author, consisting essentially of a bascule bridge, the leaves of which are made to slide back, with their centers of gravity moving always in a horizontal line and revolving about them until they reached the wide open position, of which type there is a bridge in Milwaukee already completed, and another for which George H. Benzenberg, M. Am. Soc. C. E., has prepared plans of a structure without any towers. By this arrangement the distortion by necessity for absolute adjustment and danger from settlement is considerably relieved.

Charles E. Emery, M. Am. Soc. C. E.,

desired to add his testimony to the very thorough way in which this subject had been presented. In regard to the type of bridge, he thought that those engaged in actual construction were best fitted to criticise, but as there seemed to be a difference of opinion among them, he might be permitted to remark that apparently something more in the way of land damages might have been allowed, and a simpler bridge placed at that site. The raising of a span of only 130 feet to such a great height would seem to be unnecessary, for had the whole span been lifted in one direction, the tower spanning the river would not have been required and the load to be lifted have been reduced one-half. It might be, however, that the conditions were much worse than appear in the paper.

T. J. Long, M. Am. Soc. C. E.,

said that the only point which occurred to him was the statement of the author that one of the advantages of this type of bridge over the bascule and jack-knife lift-bridges is that it can be paved, while the latter cannot. His impression was that the Tower Bridge, of London, which is a bascule bridge, is paved, and that the two bridges of the jack-knife lift type in Chicago are also paved.

J. Sterling Deans, M. Am. Soc. C. E.,

said that he was not prepared to discuss the details of construction, but would state that he had heard objection made to this special design of draw, by one of the assistant engineers of Chicago, on account of the great cost for operation. He had since heard, however, that a large proportion of this cost was due to some defect or inefficiency in the machinery and not due to any defect in the design of the structure proper.

Lee Treadwell, Assoc. M. Am. Soc. C. E.,

remarked that in regard to the question of wire rope tests made were very interesting, and he was sorry that they were not embodied in the paper. The author expected, however, that their results would be given in the form of a discussion by G. W. G. Ferris & Co., who made the tests. When tested the rope parted at a point between and removed from the fastenings, showing thereby that its full strength was developed, and that the efficiency of the fastenings was all that could be desired. According to his recollection the maximum strength of a 1¼ inch steel cable was found to be 175,000 pounds, or about 15 per cent. less than its estimated strength. The breaking strength of wire rope, as given in manufacturers' catalogues, is generally arrived at by multiplying the strength of one wire by the number of wires in the cable.

He desired to say that about six weeks ago he went up on the Halsted Street bridge, and that the buffers worked in a perfect manner, there being absolutely no reaction such as is felt when an ordinary passenger elevator is brought to a stop.

Answering Mr. Buck, he said, that in working up the design for a proposed lift-bridge at Duluth, which finally led to the Halsted Street bridge, a number of different designs were carefully considered by the author, one of which was with a fixed span at the top of the towers, but, that when the cost of the span, together with the cost of the suspended floor and all the necessary cables, drums, counterweights, pulleys and attachments were considered, it was believed that there would be little or no saving in cost over the movable span. He thought a more serious objection, however, to the fixed span and suspended floor was that the long chains or cables going down to support the floor could not be protected from the weather and the swaying action of the wind. Moreover, a floor 130 feet long and suspended by cables 155 feet in length would be seriously lacking in rigidity, especially under the passage of heavy coal wagons and similar loads. The design was therefore abandoned as being entirely inadequate to meet the requirements of the case.

The unusual conditions that affected the Halsted Street crossing he considered to be eminently favorable to the lift-bridge type of construction. A rotating draw, with its pier and protection piles occupying a space 60 feet wide by 200 or more feet long in the middle of the river, would interfere seriously with navigation interests, for the river is both narrow and crooked at Halsted Street. A counterbalanced swing span, with one short arm and the pier on the shore, could probably have been constructed for a little less than the cost of the lift-bridge, but the damage to private property and the occupation of about 300 feet of wharfage would have more than offset the saving. Moreover, such a span, not permitting of a complete rotation through 360 degrees, would require more time to open and close. There being continuously heavy traffic on Halsted Street, the item of time in opening and closing any bridge for the passage of boats was therefore a most important consideration. The lift-bridge was built entirely within the street limits, there being no damage to private property and no interference with boats receiving or discharging cargoes at the adjoining wharves. He stated, also, that so far as he was able to learn when in Chicago, the lift-bridge is giving better satisfaction to both navigation interests and to the general public than is any other bridge over the Chicago River. The average time that street traffic is interrupted for the passage of a vessel at the lift-bridge is said to be less than the corresponding time at the swing bridges.

As to the cost of the bridge, he said that no bridge builders in this country had previously had experience with a structure of this kind, and consequently they bid with a large margin for contingencies. In addition to this, the contractor was required to give a bond for the successful operation of the bridge, according to the requirements of the plans and specifications, namely, that it should be raised 100 feet in 50 seconds. The approaches and machinery house were included in the cost of $200,000. He believed that the bridge could now be built for something like $50,000 less than that amount.

In regard to the operation of the bridge, he was told recently by the day signalman on the span, that, excepting with the engines, not the least difficulty had ever been experienced in operating the bridge. Some weeks ago the main driving pinions on the crank shaft of the engines were broken, through rough usage by an inexperienced engineer, and, as a consequence, the span remained at the top of the tower for a period of 36 hours, at the end of which time the repairs were completed and the bridge again put in operation. He said another reason that the engines have not given perfect satisfaction is, that they are run at a much higher rate of speed than their designers ever intended that they should run. Instead of raising or lowering the span at the rate of 2 feet per second, as required by the specifications, it is generally moved at the rate of 3 or more feet per second; hence there is a tendency to shake the engines to pieces and to loosen the connections.

He further remarked that the force required to operate the bridge is a large item in the expense account, three engineers, two signalmen, four policemen, and one man to shovel coal, clean the machinery, oil bearings, etc., being required to make up the shifts for 24 hours. The cost of operation is said to be about $1,000 per month during the navigation season. He understood, however, that the author would in future designs use electrical power and make such other modifications as to reduce the operating expenses to about one-half of the amount given, depending on the weight of the bridge and the local requirements.

Foster Crowell, M. Am. Soc. C. E.,

thought that the author in speaking of the jack-knife construction refers to a structure of two parallel folding girders, and that those spoken of by Mr. Long were modifications of the bascule type. The old-fashioned jack-knife bridge evidently could not be paved unless the supports were made entirely free from the floor, which is impracticable. The pavement on the Halsted Street bridge he believed was wooden blocks, which would not be a great weight on a bridge of this length. While a permanent pavement would be a desirable thing, it does not seem to be a very serious matter.

He understood there was a report that the annual expenses of maintaining the Halsted Street bridge would be about $15,000, and that when a bridge of the same type as this was recently in contemplation, not far from New York City, the authorities abandoned the idea on account of this expense.

CORRESPONDENCE.

T. W. Heermans, Esq.,

said that in describing the construction, erection and operation of the machinery designed and erected by the Crane Elevator Company for the operation of the Halsted Street lift-bridge, it would, perhaps, be well to consider the subject under the following heads:

1st. The general plan and arrangement of power-house.
2d. The determination of power required.
3d. Type of engines to be used.
4th. Methods of connecting gearing to drum shaft.
5th. Mounting of the drum shaft and gearing.
6th. Friction clutch used in connection with gearing.
7th. Method of piping and running engines.
8th. Counterweights.
9th. Method of setting counterweights.
10th. Cable fastenings.
11th. Method of connecting cables to span.
12th. Water counterbalance.
13th. Hand-power operating device.
14th. Signaling device.
15th. Peeper.
16th. Suggestion for ascertaining power required for operation.

First.—In the general plan and arrangement for the machinery in the power-house, ample space had been set aside by the engineer for the machinery, and consequently the only requirements were that the best use possible be made of this room, so that the machinery be readily accessible for maintenance or repairs. This was accomplished by placing the boilers on one side of the engine-room, with their fire doors toward each other, and sufficient space between them for fire irons or for renewing the flues in the boiler when necessary.

This arrangement of boilers allowed the engines to be placed centrally in the engine-room, with their working end readily accessible and near the firing space. It was so arranged that the man in charge of the machinery, in caring for his boilers, would also be near the engines and operating levers when any signal is given from the operating house on the span. The engines were connected with the drum shaft by spur gearing, and are clearly shown on the plans submitted with the paper, which show, also, what other arrangements have been made with respect to the machinery.

Second.—The determination of power required for operating the span has been very thoroughly gone into by the author in his paper. The figures made by him, or rather the results arrived at, were similar to those obtained by the writer. The proportioning of the gearing is such that the piston travel of the engine is to the motion of the bridge or span as 500 is to 158, making the pressure available on one piston equivalent to a disturbance of the balance between the bridge and the counterweights (with 100-pound boiler pressure and the span uniformly belanced) about 20,000

pounds. This appears, from all experiments made, to be ample for overcoming the inertia and friction. No absolute data has yet been ascertained as to the amount of power required to start, accelerate and keep the bridge in motion, but this matter is now being considered by the city engineer, and experiments will doubtless soon be made that will give reliable data.

Third.—The type of engine used for operating the machinery is one built by the Crane Elevator Company, and used largely in the steel plants for operating the transferring cables, cranes, etc., and is of the steam reverse type. While this engine is not as economical in the use of steam perhaps as some link motion engines, its construction is so much more simple that, like the valve motion used with steam pumps, it has come largely into general use where such engines are employed, and receive a maximum amount of use and minimum amount of care.

Moreover, as the engines are standing for a large portion of the time, it is easy to make steam for them, as the fires under the boiler may be kept in more uniform condition.

Fourth and Fifth.—The method of connecting the gearing to the drum shaft was such as to admit of the removal of any of the gears without disturbing the machinery. In other words, should any one of the gears forming the two trains of gearing connecting the engines with the drum shaft be broken, it might be removed in a short time without disabling the operation of the span.

Sixth.—The friction clutch used in connecting or disconnecting the engines from the drum shaft was of special design, and made necessary by the position in which it was placed. These clutches are of the Weston type, and are set up by a wedge and toggles operated by a screw passing through a stationary nut.

Seventh.—The plan or method of running the piping was arranged so that both engines are fed from a main header or drum supplied by independent pipes from the two boilers, thus making it possible to use either or both the boilers, as well as either or both the engines. In addition to the ordinary throttle valve, which is operated by a lever easily reached from the operator's position, a small by-pass valve was supplied, having an area of a ¼-inch pipe. This valve is kept continuously open on both engines, so that the chests of these engines are kept supplied with steam at boiler pressure. The chests are also provided with steam traps for removing the water of condensation. It will be readily understood that with this connection, either engine can be placed in commission instantly by opening the throttle valve. In practical running it is customary to keep both engines in gear, allowing the one not used to be driven by the other. The small quantity of steam passing through the ¼-inch by-pass valve, being of so small importance, is immaterial, and the advantage gained of being able to throw in the engine not in use instantly by opening the throttle valve is of much more importance.

Eighth.—The arrangement of counterweights was very clearly explained by the author. These counterweights, it will be remembered, are in 16 groups, each group being carried by a double cable, having its bight at the counterweight, and the two ends at the suspension pin on the span.

Ninth.—The method of settling these weights was as follows: Wrought-iron stirrups were placed over a girder built in the construction of the tower near their highest point of travel, and to these suspension bolts I

beams were fastened that would bring the bottom of the counterweights to a point 1 foot below their highest position. The weights were then raised to the platform thus constructed, and placed in their cage or guides by a small contractor's engine. The counterweights when thus set form four groups, each group containing 44 weights, and each weight weighing about 3,200 pounds, and were then ready for the suspension cable fastenings.

Tenth and Eleventh.—The cable fastenings for these suspension cables have been referred to by the author, and consist of an equalizing sheave on each of the four sections of each group, and clamps through which the suspension pin passes at the opposite or span end. These clamps were rendered necessary by the distance between the cables where they passed over the sheaves, this distance being only 2½ inches. It was necessary to get some fastening that would securely hold the ends of the cables, and not occupy more room than the 2½ inches mentioned above. These clamps are made of cast steel, and are clamped together with reamed bolts. The cables were measured to length, and fastened in them before they were delivered at the bridge, the only work required at that point being the lifting of the cables in position and the driving of the pin through the clamp on the span. When this was done, the span, which was then in position, was lowered by jack screws until the suspension cables were taut. It will be remembered that the counterweights were within 1 foot of their highest position, consequently the span, when lowered on the cables, had yet 1 foot to move before it reached its lowest position. This was easily accomplished, allowing the sustaining platform under the weights to be removed, and the operating cables from the power-house to be attached to both the span and the counterweights.

Twelfth.—The water counterbalance and its connections, mentioned by the author, consist merely of balance tanks on the span and a 2,000-gallon tank in one of the towers of the bridge, with supply pipes that can be used at the lowest position of the span or at its highest position. The tank on the tower is kept supplied by the boiler pumps in the engine-room, either of which can be used. It is also arranged so that steam can be admitted for the purpose of keeping the tanks thawed out in winter.

Thirteenth.—The hand-power device is simply a series of pawls arranged in much the same manner as on a ship windlass and for the same purpose. The proportion of lever arms is such that the power of two men applied to the end of the brake handle will operate the bridge.

Fourteenth.—The signaling device is operated in much the same manner as similar devices used on shipboard, with the exception that its connection to the moving span must be in some manner that will admit of transmitting signals while the span is in motion.

Fifteenth.—The peeper, which is referred to in the paper, has been set in position on the bridge, but, owing to the use of soft coal by the tugs and steam barges, it is not entirely satisfactory, as it is difficult to keep the lenses clean, and without being clean they are not satisfactory. It is not difficult, however, without the use of the peeper to so gauge the height of approaching vessels as to raise the bridge to the necessary height to an absolute certainty, and in actual practice the operator acquires the necessary skill without the use of the peeper.

Sixteenth.—In regard to ascertaining the power required for operating the bridge, many plans have been suggested as to the most feasible test.

The writer has suggested that a hydraulic cylinder be placed in the position of the friction clutch and used as a driver in actuating the drum shaft. A pipe leading from this hydraulic cylinder to a recording gauge could be made to draw a card of the pressure delivered at that point. This card could be divided, the spaces corresponding with the seconds during which the bridge was in operation, and points made on it with every revolution of the driving shaft to which the hydraulic cylinder is attached. With this it would be extremely easy to ascertain exactly the amount of power required at any given second, as well as the power required in starting and accelerating the motion. Such information would be extremely interesting, and it is to be hoped that at some future time such data will be obtained.

Samuel M. Rowe, M. Am. Soc. C. E.,

said that as his connection with the erection of the Halsted Street lift-bridge was in a certain measure vicarious in this, that he represented the designer, so far as minor matters, in connection with the work that did not especially require his personal attention, and as the author had treated the matter of mechanical construction and operation of the bridge quite exhaustively, it would seem most proper and profitable that he should confine himself in discussion to those side matters of which he had especial knowledge and which might possess some interest in practical engineering.

A cursory examination of the river bed by means of a long iron rod showed a mean depth of water over the whole breadth of channel of about 18 feet, but below this the earth was very soft, allowing the rod to penetrate some 6 feet further almost without pressing it.

It was first understood that rock existed here at a depth of 35 to 40 feet, and on this basis the plan contemplating pile and grillage foundation for the main pier was based; but, after pressing the matter, permission was obtained to make two borings, one at each dock, to definitely determine its level.

One hole was put down about midway between where the two main caissons were since sunk at the south tower, driving 4-inch casings to depth of about 20 feet. An earth auger was used to clean the pipe and to extend the boring below.

Progress of the boring was slow and tedious on account of the yielding nature of the clay, and it was only by repeated returns of the auger that it was penetrated, the walls closing in immediately on withdrawal of the auger. At about 26 feet a firmer clay was found and rock was supposed to be struck, but which proved, on sinking the caissons, to be fragments of limestone embedded in the hard clay overlying the rock.

The boring at the north bank showed much the same formation, the harder stratum overlying the rock being slightly thicker. On reaching the rock with the pneumatic caissons its true elevation was found to be at about 30 feet below Chicago datum at the south piers and about 1¼ feet deeper at the north piers.

He said that in relation to a foundation they reasoned thus: Using Chicago datum, which was here only a little below ordinary water level, and placing the elevation of the bottom of the grillage, which would be the elevation of the cut-off of the piles, at minus 15 feet there would be a length of pile of only from 14 to 16 feet, four-fifths of which would be in a very unstable material. The remaining one-fifth, should the pile reach the surface of the solid rock, would hardly afford that degree of stability that would seem to be required to insure against lateral movement of the pier.

He thought that when it is considered that the bridge is a piece of mechanism, in which any distortion from this source would be exceedingly mischievous, if not fatal, it would be seen that safety requires that the masonry should go to the rock. The fact that these piers may be subject to violent shocks from collisions from lake vessels of 4,000 tonnage and over, either on the pier or on the span, gives force to the objections to the plans originally made.

Consequently four pedestal piers 12 feet square were substituted for the two long ones and timber caissons were built on shore, launched into the river and floated into position. These caissons were built 18 feet square, of hemlock timber, the walls consisting of a double wall of 12-inch square timber chamfered off at the lower 2½ feet, forming a cutting edge and roofed at about 8 feet, with three courses of 12 x 12 inch timber. The crib was built above the roof of the working chamber, a single wall of 12x12 inch timber with ties of the same crossing alternately in the center, to such height as was necessary to receive the base of the masonry. Of course this could only be approximated, and when the caisson reached the rock, some of the masonry courses had to be recut.

After anchoring the caisson in place, concreting was commenced and continued until the crib was filled, after which the masonry was commenced, laying courses slightly larger than the neat dimensions of the pier, to meet any tilting movement of the caisson in sinking.

When the caisson cutting edge was resting on the rock and all excavation cleaned except such fragments of rock or boulders as could be utilized in filling, all interstices under the cutting edge were chinked with concrete deposited dry and rammed into place, after which the working chamber was filled with concrete in the same manner, except that water was increased as leakage diminished. As soon as the caisson was fully sealed and such portions of the working shaft removed as was practicable by means of a wooden curb built around it, the masonry was brought in to its neat dimensions and finished.

The anchor bolts were set with a template and built into the pier.

The masonry was built of Cleveland (Berea) stone of best quality in courses from 2 feet to 18 inches in thickness, the stone being laid to form the face and angles, the backing consisting entirely of concrete well rammed.

The cement used was a German Portland—the Sphinx—used in the proportion of 1 part of cement to 2½ parts of good, medium sand, tempered before adding as much broken stone as it would take, the result being a very excellent quality of concrete.

The question of guarding against the movement of the abutments by reason of the tendency of the river banks to press toward the river channel, thus bringing into play another possible disturbing element, was early raised.

He said that most engineers are aware the Chicago River was originally a shallow slough or creek, and in making the harbor and docks as they are now found, the channel has been deepened, and large quantities of earth have been removed from the channel and deposited on the bank adjacent, and although supported by a row of piles driven close together, timbered, and in most cases anchored to piles some distance back, yet there is a tendency to slide toward the stream.

Not only does the material removed become soft and unstable, absorbing water readily, but the formation of which the river banks consist being mostly a soft, stiff, tenacious clay, shows this same tendency, only in a less degree, to move toward the unsupported side.

Many instances could be cited where the wing wall of the abutments of the Chicago bridges have been broken and the face wall tilted toward the channel, and it is presumed that the same will hold true as to any heavy building erected on the dock, only perhaps in a less degree.

To guard the bridge pier and the machinery room against displacement from this cause, he stated that a clear space had been preserved between the machinery room and the abutment, and an elaborate anchorage was planned for the abutment.

Five sets of four piles each were driven deep into the ground about 40 feet back of the face of the abutment, and two iron rods from each set of piles connect to cast-iron washers bedded in the concrete abutment and drawn tight by nuts at the anchorage.

Notwithstanding these precautions, the wing walls have cracked through the entire depth, showing a slight tilting forward. It seems as if the anchorage should be heavier and should also be placed deeper and be reinforced by a mass of masonry concrete, to render it entirely effective.

The measurements for the location of the bridge were made with a steel tape, which was carefully compared with standard measuring rods furnished by the Pittsburg Bridge Company and found to agree exactly with 25 pounds pull upon the tape, the tape being supported; and the rods and the tape were found to agree with a standard 200-foot measure in the corridors of the City Hall at a temperature of 70 degrees Fahrenheit.

The base line for the location of the bridge was an arbitrary line parallel to the center line of the street, both north and south, but, owing to the jog in the street at the river crossing, this base line corresponded with the curb line on the west line of the street northward, and on the east curb line southward. Using a point on this base line near the middle of the river as the middle of the bridge, the center line of the bridge was fixed by calculation at an angle of 12° $16\frac{3}{10}'$ to the right, and reference points on the street were set from which all work was located. A practicable point was chosen on each dock by which two auxiliary base lines were turned from this center line of the bridge and intersecting the first base line, which enabled the engineer to fix convenient points for location of the main piers, etc. The true centers of the main posts of the two towers corresponding to the centers of the caissons were the main points located, and when erection commenced these main posts were very carefully set.

The angles were carefully turned with the transit and calculated, and, when practicable, distances were checked with the steel tape.

From this basis every part of the foundation was laid off, even to the anchor piles back of the abutments.

The main posts over the piers were first set, the inclined posts following, and when the first section of the tower was complete, the inclined posts were adjusted by means of the large screw at the base until the main posts were plumb, after which the erection was completed, the towers reared nearly 200 feet high, and the truss joining the towers raised as a whole and bolted into its place without the least delay, showing that the columns were accurately located, that they were truly plumb and that the shop work of the Pittsburg Bridge Company was accurate. This result was creditable to the bridge company's engineer and to Mr. Kellog, Assistant City Engineer, who did all the instrumental work on the location.

During the planning and erection of this bridge there was a feeling of doubt as to the result, a feeling of wonder at the audacity of the design, and incredulity as to its success. This was owing largely to the great mass that it was proposed to handle and the very considerable height to which it was to be raised, and, more than all other considerations, its controllability —in short, whether it could be handled promptly, moved quickly, and brought to rest safely.

W. W. Curtis, M. Am. Soc. C. E.,

remarked that the problem of the erection of the Halsted Street bridge, so far as the towers were concerned, was by no means an easy one. At the base about 40 feet square, at the top 180 feet above, the tower was less than 11 x 40 feet in the clear. The members to be handled were in some cases over 58 feet long, the main post sections being 48 feet long, and weighing over 5 tons. The best method of handling this work seemed to be by means of a traveler to pass up inside the tower; and such a traveler was designed 12 feet x 30 feet, in plan 40 feet high to the foot of two derricks, placed on the top. The width of 12 feet was too great to clear the top, but it was intended to erect all but the cross girders between the tops of the rear columns with it, and then handle these and the large sheaves by derricks erected on the top of the work, then up. The traveler was erected on the ground, one section of tower put up, and then, by means of blocks attached to the top of the four columns in place, the traveler was hoisted bodily through two panels, and supported on beams running from front to rear face of tower. This was repeated to the top, three hoists in each tower being required. This traveler weighed 20 tons, and as the drift between blocks when raised into its new position was only about 12 feet, with the blocks attached to the bottom of the traveler, which extended above some 60 feet, and during the lower lifts with a large side pull, due to the tower being much wider than the traveler, the operation was one requiring great care. To add to the difficulties, the first lift made, after being completely successful so far as the raising was concerned, through carelessness in placing on the beams on the second level, resulted in a complete wreck of the traveler, with loss of life. Being satisfied that the plan adopted was the correct one, a new traveler was built, and an attempt made to devise some attachment which would make a repetition of the previous disaster impossible. After consideration of various schemes, automatic stops, etc., such as are in use on elevators, a system of counterweights was adopted. A snatch block was attached to the same chains to

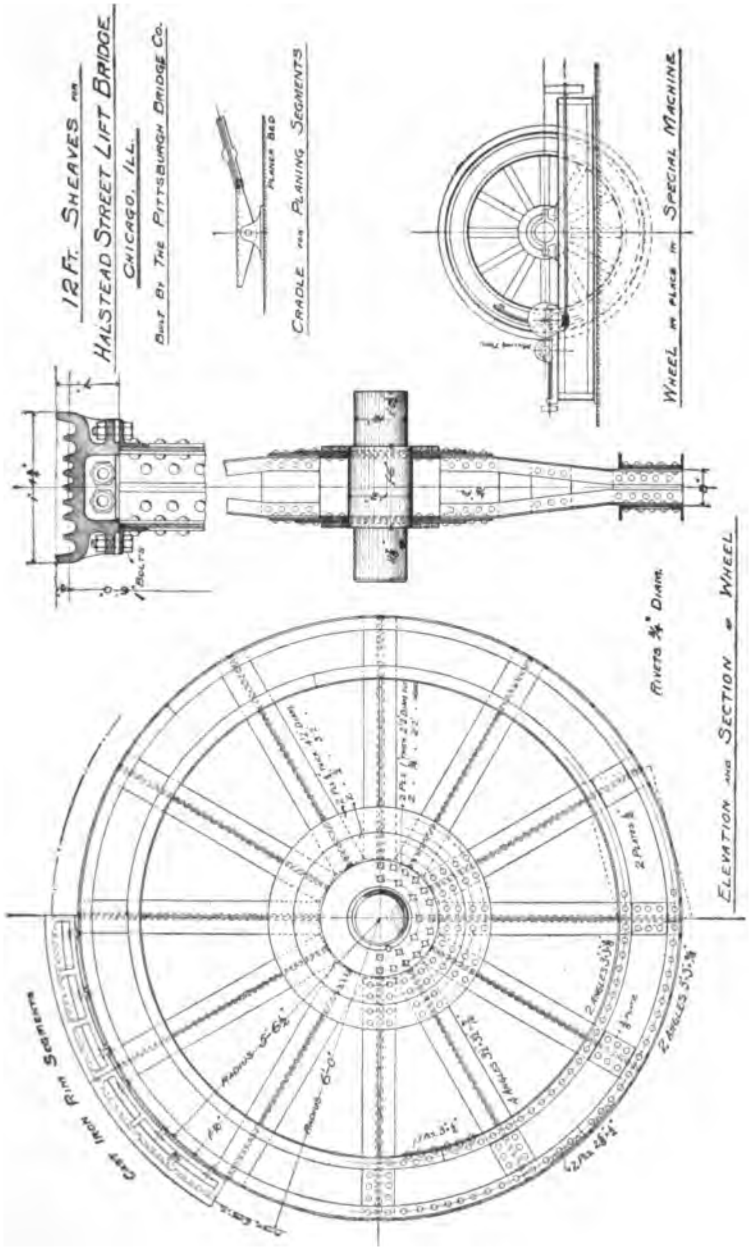

12 Ft. Sheaves for
Halstead Street Lift Bridge
Chicago, Ill.
Built by The Pittsburgh Bridge Co.
Cradle for Planing Segments
Planer Bed
Wheel in place in Special Machine
Bolts
Rivets ¾" Diam.
Elevation and Section of Wheel
Cast Iron Rim Segments
Radius 5'-6½"
Radius 6'-0"
2 Plates
2 Angles
2 Pls.

FIG. 7.

which the blocks for hoisting the traveler were fastened, and through these was passed a steel cable, one end attached to one of the corners of the bottom of the traveler, the other to several yards of stone threaded on an eyebolt. These four counterweights weighed slightly less than the traveler, leaving a very small amount to be handled by the four lines carried to the engine. Other lines attached to the counterweights and carried to the ground and passed around snubs gave absolute control of the machine, regardless of the engine. It was soon found the time to attach the counterweights was a small item, and the added security fully compensated for the lost time.

He thought that the expense of erection of such a bridge as this is very heavy, that possibly there might be some more economic method than that described, but he was not prepared to say that he would follow it in another bridge. There are various slight changes in design, which would much simplify the erection if the same method was followed.

The main sheaves, built up of plates and angles, are worthy of illustration, as being something new, at least as far as his knowledge extends, and well adapted for special uses. Such a sheave would be desirable only where the load to be carried by it was excessive; or possibly where a high velocity was necessary. It seemed at first that a cast sheave could be made to answer the purpose, costing less, but on asking prices on such a construction, it was discovered that the steel wheel could be built cheaper than the cast one. As an illustration of a bridge shop's method of doing machine work, he offers the following description: By referring to the drawing of the sheave, Fig. 7, it will be seen to consist of a cast-iron rim resting on and attached to a steel rim of plates and angles. This again is supported by steel spokes of four angles running to a steel hub. The steel shaft and hub plates having been carefully finished, the sheave was built up in a special machine, as shown. The hub piece being keyed on the shaft, this was placed in the trunions of the machine, the spokes and rim added, bolted on, the wheel revolved and trued up. The hub plates were turned on both inside and outside edges, and the spokes were milled off on inner ends, and close contact with hub plates secured. After being made perfectly true, the holes were all reamed by machine, the rivets driven by hand, and the rim milled off. The interior surface of the cast rim having been previously planed by use of the cradle attachment to an ordinary bed planer, shown in Fig. 7, the sections were attached to the wheel, the holes reamed for turned bolts, and the wheel again revolved, with the milling tool replaced with one which turned out the eight grooves at one operation. When completed, the rim sections were all match marked and numbered, removed and shipped loose. The result when the sheaves were in place on the towers was very satisfactory and creditable to the carefulness of the shop superintendent, Mr. A. T. Nichols.

He remarked that one of the many points of skepticism as to this bridge on the part of the general public related to the effect of wind on it. And while to an engineer such evidence is neither necessary nor conclusive, it was worthy of notice that during the construction, the span, with the floor and all other surfaces which would be exposed to the wind when the work was complete, was hoisted to the highest position and left up at night for about a week, during which time occurred one of the most severe wind storms ever experienced in Chicago.

In such a structure the dead loads in the towers are so great and the necessary bracing to support the main section so large, that the wind does not enter into the question of design.

He called attention to the fact that the author had very clearly indicated the points of merit in lift-bridges. They are not adapted for general use, and cannot pretend to compete with a draw-bridge where this is admissible. For special locations, however, he believed their advantages are great, and for the condition of a railroad crossing, where a center pier is inadmissible, and the span over 100 feet, such a design is far superior to any other.

He further remarked that the only unfavorable criticism that has been passed on the Halsted Street bridge since its practicability and efficiency were demonstrated mechanically has reference to its first cost and operating expense; but that for both of these there is ample excuse in this particular instance, and the improvements provided for in future designs will modify greatly these objections.

E. Sherman Gould, M. Am. Soc. S. E.,

thought this paper and its discussion was very interesting. In commenting upon it, he wished to do so under great reserve, since the structure belongs to a class of work somewhat out of the line of his own specialties.

The oral discussion, at the time of reading the paper, turned mainly upon the design of the draw, that is, as to whether the principle of the direct, vertical lift, the tipping up on end, the horizontal swing, or the doubling up, or "jack-knife," idea, is the true one. It is evident, *a priori*, that in this, as in all other engineering problems, local circumstances enter as important factors—frequently controlling ones. He would be willing to take it for granted that an important engineering problem so carefully studied on the ground by an acknowledged expert, as this was, had received the best possible solution for that particular case.

But passing to the general thesis, it would seem that the direct lift has much to recommend it on its own merits. The author claims that the time consumed in operating such a bridge is about 30 per cent. less than for a corresponding swing-bridge. This, no doubt, applies to the particular case, but if the proposition can be generalized, and made to apply to the class, it constitutes an advantage that it would require many drawbacks to offset. A draw-bridge is at best a makeshift, and in a busy city an almost intolerable nuisance, and whatever system shortens the duration of the interruption to traffic which its operation occasions must be, on the face of it, the best. One point struck him at once: There must be many craft which only lack a few feet of going under the draw when in place. For these a very short hoist suffices; whereas, in other systems, so far as known to him, the draw must be either shut or open to its full extent. Indeed on an emergency the draw could be lifted when loaded, which would be impossible with any bascule system.

It seems clear that the strains in the lift draw must be more uniform than in any other system. There is no change in their character, whether it is open or shut. As a mechanical principle, the direct vertical lifting of an object seems the simplest and smoothest way of removing it, when it is desirable to disturb the object as little as possible.

The comparative cost cannot, he believed, be determined upon general principles; each case must be a special one. He would be inclined to think that the operation of a lift draw would be nearly always more satisfactory than that of any other system, but that its cost might frequently be the greatest.

F. W. Wilson, Jun. Am. Soc. C. E.,

remarked that the author states that "should the rigging of the vessel, however, strike the span, the effect will be simply to break off the masts without injury to the bridge." It appeared to him that the effect of such a collision is possibly underestimated, although the author states that it has occurred once with the results mentioned. The use of wire rope in the rigging of vessels is now so common that if the masts should be well stayed by wire guys, it would seem that the effect might even be serious, particularly if the wire ropes became entangled with the truss span, and in case the headway of vessels was such as to make a sudden stop impossible.

He would like to inquire how it occurred that when the engines broke down and the span was left suspended for some hours that the many devices described in the paper for meeting such emergencies were not called into play. For example, the water ballast, the additional counterweights, and the hand-operating arrangement.

He thought that a detailed statement of the total cost would be an interesting addition to the paper, and that it would at least be more satisfactory to know how much of the $200,000 was expended for substructure.

Samuel Tobias Wagner, M. Am. Soc. C. E.,

stated that in reading this valuable paper his attention had been attracted to the following general points which are of interest.

In all large cities where swing, draw, or lift bridges must be used there should be laws requiring the use of automatic gates across the open ends of both roadway and sidewalks when the bridge is open for the passage of vessels. Such places are specially dangerous to street traffic of all kinds, and some suitably designed automatic gates should be used wherever it is practicable. He thought it is rather surprising that in a city operating as many movable bridges as Chicago there are no existing laws bearing upon this subject. In a railroad grade crossing there is a chance of the trespasser not being struck by a train, but the result of stepping or driving off the open end of a movable bridge is a sure one.

The matter of the operator in the house on the bridge being sure that his signals to the engine-room have been understood is one of importance under the existing conditions, and repeating the signal is a good way of avoiding trouble. He remembered having seen on a lake steamer some years ago an automatic electrical device connecting the pilot-house with the engine-room, which enabled the pilot by means of different sounding bells by night, or by colored signals by day, to tell immediately whether the engineer had obeyed his signal. The use of this device was occasioned by a steamer running into a swing-bridge at Buffalo through a misunderstanding by the engineer of the pilot's signal. This was only another instance of the value of automatic machinery for safety appliances.

In specifying the steel to be used for a bridge of any kind, in view of the existing knowledge of the metallurgy of the metal, he would always specify: "All steel to be manufactured by the open hearth process, and all eyebars to be of acid open-hearth metal," and thus exclude the use of the Bessemer process. This is on account of the uniformity and homogeneity of the open-hearth product as compared with the Bessemer. The words of Mr. H. H. Campbell, in a paper on the "Open-Hearth Process," read before the International Engineering Congress in August, 1893, and published in the Transactions of the American Institute of Mining Engineers of that date, express his views.

"Uniformity and homogeneity, therefore, are two of the most important factors in the comparison of the merits of the Bessemer and open-hearth product; but unfortunately no conclusive testimony can be given to the skeptical or even the careful mind, although ex-parte arguments are easily constructed. No one conversant with the facts doubts that Bessemer heats can be made which are as homogeneous throughout as any open-hearth charge as was ever melted. No one doubts that in good practice the proportion of Bessemer heats which are not homogeneous is a small percentage of the whole number. But the question is not as to the homogeneity of 99 heats; it is about the quality of the hundredth. And it is not one single test of this hundredth charge that it required, but a large number of tests taken from all parts of the cast. One piece of steel differing radically from the rest wipes away all favorable arguments drawn from any number of other tests indicating homogeneity. The foregoing comparison of the open hearth and converter may not be a convincing argument against Bessemer metal. It may justify engineers in using the cheaper article in many structures, but it will also sustain the more cautious members of the profession who refuse to incur a known or a probable risk."

He added that the author does not say whether he has specified any chemical analysis for the steel in this structure, and it would be interesting to know what was done in this direction. Probably it is not fair to the manufacturer to give both physical and chemical requirements, but in view of the history of the failures in steel, it does not seem safe to omit giving a reasonably low limit for phosphorus in the specifications.

Horace E. Horton, M. Am. Soc. C. E.,

remarked that the author gives portions of the specifications for the work. In the way of discussion it occurred to him that further extracts from the specifications under which this work was built might be interesting.

"Contractor" * * * "for the machinery" * * * "shall give the city of Chicago a bond for the sum of $50,000" * * * "as a guaranty for" * * * "successful operation of the bridge, and this sum shall be collected from the bondsmen and retained by the city of Chicago in case said contractor fail to make the bridge operate successfully."

"Substructure is to be paid for upon completion and acceptance thereof by the commissioner of public works, but the remainder of the work will not be paid for until the bridge is completed and accepted."

"Hydraulic buffers are to be designed by the engineer and contractor's expert jointly." * * * "All apparatus or machinery not herein specified which may hereafter prove necessary to operate the bridge properly and satisfactorily."

"At any time before the bridge is accepted, should the commissioner of Public Works decide that any apparatus not covered by this specification is necessary to the successful operation of the structure, such apparatus shall be furnished and put in place by the contractor without extra charge."

Such, he wished to state, were the conditions presented to contractors. They were asked to give bonds in the sum of $50,000 forfeiture upon failure to make the structure a success, and no prudent man will undertake work under such stipulations at ordinary profits. There were no plans of machinery. Several tenders were, however, made for the work under the harsh conditions outlined.

The only detail of the fixed structure the author describes at any length is the ball and socket screw adjustment of the rear bent of the tower, which he implies cost extra money. The sketch Fig. 8 clearly shows adjustment to be impossible, except as the pedestals are moved upon the masonry. He ventured to suggest that the author in future designs for lift-bridges will eliminate the ball and socket screw adjustment for back bent of towers, because there are many ways to accomplish the adjustment, which will "adjust" beyond any question or argument.

He believed that the ability of the Halsted Street bridge to withstand the shock of collision with moving vessels can best be shown by experience.

There can be no argument, he thought, as to the necessity of something other than the pivot draw-bridge under the conditions existing in Chicago. The Chicago River, which is the harbor, approximating 200 feet wide between dock lines, with a demand for bridges at every street of 60 feet in width, real estate adjacent of such value as to preclude the purchase of property to allow a pivot-bridge to be swung from one side of the river. In fact, there should have been developed folding or lift-bridges twenty years ago. The public were very slow to recognize the necessity for change in design, and up to this time only four structures of the folding or lift type have been built (two completed and two approaching completion). The next few years, he thought, will see considerable evolution in design for Chicago River lift or folding bridges. The first example is the folding bridge on Canal Street, 32 feet wide by 80-foot span, which cost the city $18 per square foot of the area of the movable parts. The second structure, the Halsted Street lift span (subject of this discussion), is 52 feet wide by 118 feet opening, and cost the city $35 per square foot of opening. The third structure, Van Buren Street (not fully completed), bascule type, designed by the late William Scherzer, M. Am. Soc. C. E., 58 feet wide by 108 feet opening, cost $24 per square foot of opening. The fourth is the Metropolitan Elevated Railway span, a four-track structure of the same general design as the Van Buren Street bridge.

The Halsted Street structure has been in use for some time, and has given fairly satisfactory results, leaving much to be desired, however, in the way of economy of maintenance, as well as certainty of operation.

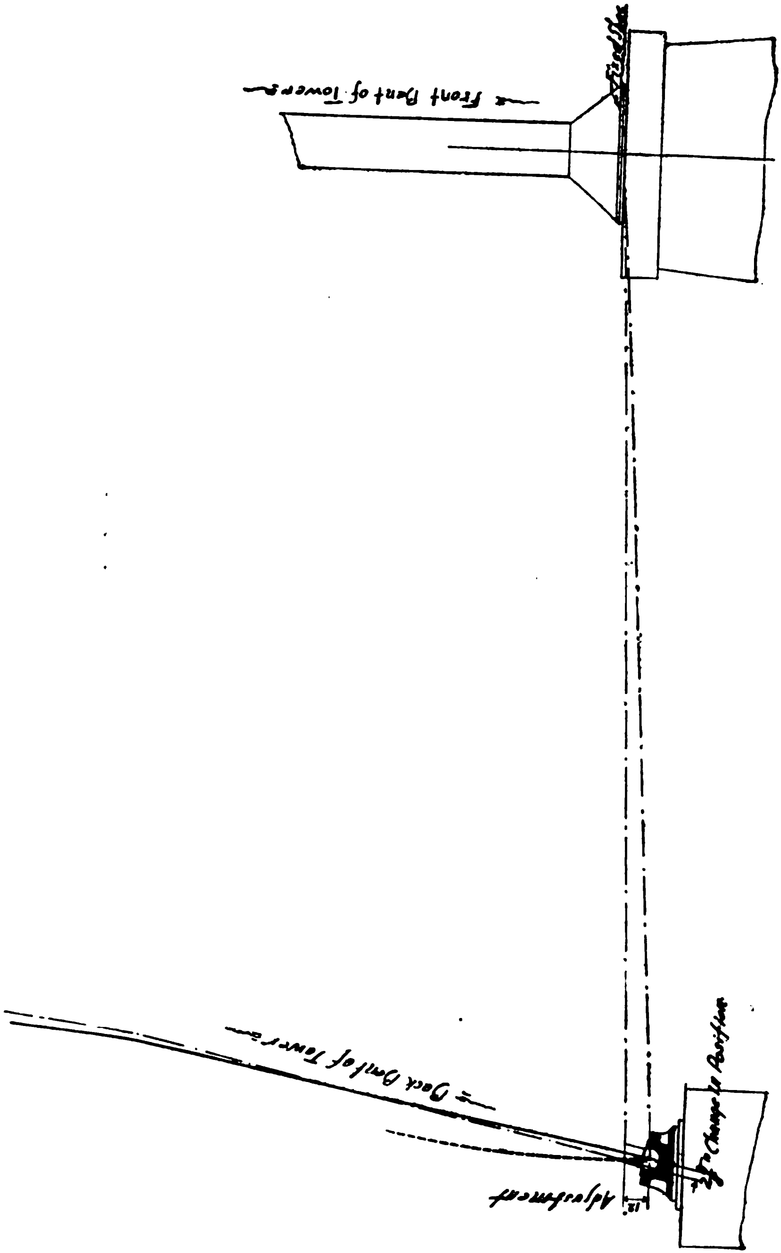

Front Part of Towers
Fixed Stop
Back Part of Towers
Adjustment
12"
3" Change in Position

FIG. 8.

He regretted that the author did not give particulars of the failure to operate, whereby the lift remained at its extreme elevated position somewhat over 24 hours. His understanding was that it resulted from the breakage of a pinion in the power operating gear. This calls attention to the fact that the hand moving appliance spoken of can be made of use at such times as the power operating machinery is in order, and not under other conditions.

As to maintenance, he thought the 14,000 feet of wire rope in use on the Halsted Street bridge, of necessity to be renewed at short intervals, was somewhat appalling, and that it is more than likely the apprehension of failure, and the certainty of the wearing out of wire rope necessary to manipulate bridges of this type accounted for the seeming want of confidence of both the public and engineers in such structures.

The only example that had come to his attention, of a lift-bridge other than the Halsted Street one, is the bridge on the West Shore Railway across the Erie Canal, at Syracuse, N. Y., designed by Albert Lucius, M. Am. Soc. C. E., and built by the Hilton Bridge Works, of Albany, in 1882, this structure being a double-track railroad bridge on a skew, 104-foot span, the lift being about 8 feet, the motive power being a water motor worked by pressure of Syracuse city water. There was an interval of fully 10 years as between the building of the West Shore railroad bridge at Syracuse and the Halsted Street bridge, which is reason for the conclusion that this class of design is not a favorite.

J. A. L. Waddell, M. Am. Soc. C. E.,

remarked that it was fortunate that Mr. Treadwell was present at the meeting at which the paper was read, for he was able to answer many of the questions raised in the discussion. On this account, in replying to the various discussions, he would omit all reference to those points dealt with by Mr. Treadwell.

Answering Mr. Skinner, he stated that his first design for rear column adjustment involved the use of "differential loose packing plates and hydraulic jacks"; but that he abandoned it for the reason that such an adjustment is troublesome to make, and would, in consequence, in all probability be neglected, while with the design adopted the trouble is reduced to a minimum.

Answering Mr. Long, he said that the folding bridges of Chicago are planked and not paved. It would be difficult to keep paving blocks in place when the entire floor is lifted continually from the horizontal to the vertical.

Answering Mr. Wilson, he understood that there had been two collisions of vessels with the Halsted Street bridge, and that the structure had not been injured to the slightest extent. A glance at the bridge is almost sufficient to assure one that no rigging, even with wire rope guys, can do it any harm.

The failure to use the hand-power apparatus when the break-down of the engine occurred was not due to any inefficiency thereof, but because it was considered best to interrupt wagon and pedestrian traffic rather than to interfere with navigation. No one imagined at the outset that the operation of the bridge would be interfered with more than a few hours; and it was only because of a complication of peculiar circumstances (involving a strike of foundrymen) that any difficulty was experienced in getting a new gear wheel.

Answering Mr. Wagner, he stated that his original specifications stipulated the use of open-hearth steel only, but that he was forced to accept Bessemer. In the building of this bridge he was by no means a free agent, so had to make many concessions which he did not approve of, deeming himself fortunate in being allowed to build the bridge at all.

If he were to enumerate all the unnecessary difficulties encountered by both the contractors and himself from start to finish, far more space would be occupied than would be permissible. He thought it sufficient to say that until the span was hung neither they nor he could feel at all certain that they would ever be allowed to finish the bridge, such being the prejudice against it on account of a preconceived notion among engineers as well as laymen that it would be impossible to move such a great weight in any reasonable time.

Answering Mr. Horton, he acknowledged that the specifications were severe and "harsh," but would say that in preparing them he had no choice in the matter, as the city officials would not consider for a moment the building of such an innovation, unless the contractor would guarantee the successful operation of the bridge.

The papers for bidding upon were prepared under high pressure, and were made as complete as the limited time permitted; moreover, the only portions of the machinery left to the contractor to design were the steam machinery with its connections to the operating drums, and the hand-power apparatus. As the contractor was compelled to guarantee the operation of the bridge, it would have been manifestly unfair to handicap him by forcing him to use steam machinery of a design and power determined without reference to him.

As for maintenance and repairs of wire rope, he believed that, owing to the large factors of safety adopted, in all probability there will be no large expenditure necessary for many years to come.

The automatic gates suggested on page 11 have since been put in for the footwalks, but not for the main roadway. They operate very satisfactorily.

In conclusion he desired to state that, while in making a design for another lift-bridge there are many improvements which he would introduce (principally in the line of economy of operation), he was well satisfied in every particular with all of the details of this structure; for everything worked just as it was designed to work, and there was no cutting or fitting necessary to ensure this result. Moreover, most of the important changes now contemplated would have been made in this case, had he been at liberty to design according to his own wishes. On this score, though, he desired to make no complaint, for he was well content in having had an opportunity to prove the practicability of his lift-bridge designs, even with the accompanying irksome restrictions.

N. B.—The following letter was published in *Engineering News* of April 18th, 1895, as a supplement to the discussions:

KANSAS CITY, MO., April 6, 1895.

Editor of Engineering News:

DEAR SIR.—My attention has been called to a point in Mr. Horace E. Horton's discussion of my paper on the Halsted Street Lift-Bridge that I overlooked in making my reply to the discussions. The reason for the omission is that the secretary of the Society failed to send me a copy of the diagram that accompanied Mr. Horton's discussion, consequently I did not recognize the importance of the accusation. Had I received the diagram, I would certainly have answered Mr. Horton's objection in my *résumé*, as I now beg permission to do in the columns of your paper.

In the first place, Mr. Horton's assumption of a play of twelve inches in the screw is manifestly absurd, for the reason that the screw at present has only fourteen inches grip, so that if it were moved out twelve inches there would be only two inches of grip left. The adjusting detail was designed for a possible variation of only an inch or two, but is good for as much as three inches on a pinch.

In the second place, Mr. Horton's method of finding the horizontal movement is incorrect, because it is not a matter of rotation. The main piers rest on bed rock, consequently no sinking on their part is possible. Then the vertical columns resting thereon are anchored down to the masonry, and are held together at their tops by the overhead horizontal girders. If any adjustment of the screws be required, it will be caused by the settlement of the rear pedestals. That settlement multiplied by the secant of the angle of batter of rear columns will give the corresponding elongation of the screw. Or, if the elongation be assumed, its value multiplied by the cosine of the inclination will give the sinking, and the same value multiplied by the sine of the inclination will give the horizontal shifting of the foot. The tangent of the inclination or batter is 0.16327, for which the corresponding sine is 0.160, which multiplied by an assumed elongation of twelve inches gives 1.92 inches for the horizontal shifting, instead of the 2⅞ inches found by Mr. Horton. If we assume three inches as the greatest allowable lengthening of the screw-end, the corresponding horizontal shifting will be forty-eight hundredths of an inch, while the sliding plates and slotted holes for anchor bolts in my detail *permit of half an inch motion in each direction.* Should this amount ever prove to be insufficient, which is highly improbable, the elongation of the holes can be easily increased by a small amount of work put on them with a cold chisel. It is evident, therefore, that the detail criticised by Mr. Horton has not the defect which he claims.

In the third place, a few minutes' computation will show that, even if we grant Mr. Horton's method of finding the horizontal motion to be right (which it is not) the gentleman was somewhat careless in his arithmetical calculations; because if we take the final difference in elevation of main and rear column feet at forty-eight inches, which his diagram scales, as nearly as may be, the horizontal sliding will be only one inch instead of the two and seven-eighths inches which he finds.

Very respectfully yours,

J. A. L. WADDELL.

COMMENT.

The Halsted Street Lift-Bridge is a peculiar and individual structure, not one of a type, since, for reasons before mentioned, it is not probable that another such bridge will ever be constructed; but some of its principal features merit more attention than they received in Dr. Waddell's paper and the discussions which follow it.

It will immediately occur to any engineer who is familiar with mechanical work that it would have cost little more to install electrical machinery, and that by doing so the cost of operating the bridge would have been greatly reduced. It is only fair to say, however, that this was the procedure advocated by Dr. Waddell and that his preference was overruled by the city authorities. Electric motors cost materially more than steam engines, but the cost of the boilers, the pumps, the steam piping, and the portion of the machinery house necessary to accommodate the boilers and the coal supply would go far toward offsetting the extra expense. It is not at all impossible that it would have proved economical to place the hoisting machinery in the towers and thus avoid altogether the construction of the expensive subterranean machinery house. The use of electric engines would make it possible for one man to operate the bridge, while the cost the small amount of electric current required for such intermittent service would certainly be less than that of the coal used to keep up steam continuously; hence the resultant saving by electric operation would be very great.

The speed with which the bridge is operated is all that could be desired, for it is commonly raised to the full height of 155 feet above the water in thirty seconds and lowered at the same speed. The calculation of the power required to operate the bridge is not a difficult matter, yet it is noteworthy that many Chicago engineers expressed their convictions before the structure was completed that it could never be made to work.

The buffers perform their function admirably, bringing the bridge to rest in either the upper or lower position from full speed without noticeable shock. They are not patented and may be freely used, consequently they should be of service in many mechanical constructions.

The provision for the adjustment of the rear tower legs was a wise precaution, but its use has never been required. It would appear easily possible to avoid the lateral movement criticised by Mr. Horton by making the adjustment vertical instead of in the direction of the post. In the light of the experience with this structure, however, it would appear that the simpler and less expensive adjustment suggested by Mr. Skinner is all that could be required.

The principal details of the structure are not unusual. It is the idea, the design as a whole, that is novel. The great height of the structure and the great weight to be lifted were adversely criticised by engineers and laymen alike; but, while a better type of movable bridge suitable for the conditions which governed the design of the Halsted Street Lift-Bridge has since been developed, there was nothing better in that day. All things considered, it is a substantial and creditable piece of work which will serve its purpose admirably for many years to come.

ELEVATED RAILROADS.

INTRODUCTORY NOTES.

Dr. Waddell presented his paper on "Elevated Railroads" to the American Society of Civil Engineers for discussion early in 1897, while the construction of the Union Loop Elevated Railroad and the Northwestern Elevated Railroad was still in progress. The preparation of the preliminary studies and estimates and the designs for these roads had required about three years, and he had previously designed the Austin Avenue Extension of the Lake Street Elevated Railroad. Before taking up this work Dr. Waddell had made a thorough study of the elevated railroads already in operation in New York, Brooklyn, and Chicago; consequently he was peculiarly well prepared to present to the engineering profession a well-rounded treatise on the older roads and their faults and the theoretical and practical considerations which should govern the design of future structures. The paper itself and personal letters from its author to many prominent engineers who were interested in elevated railroads evoked a discussion in which the chief characteristics of the designs of the earlier roads, the most favored materials of construction and processes of manufacture; and the theoretical and practical considerations which affect the design of elevated structures are treated exhaustively. It is, of course, impossible to reconcile the views of the manufacturer, whose chief purpose is to fabricate and erect the structure in the most profitable manner, and the engineer employed by the railroad company, who seeks to obtain the best possible structure consistent with reasonable cost; yet a free and full discussion not only disseminates the special knowledge of each participant and makes it available for general use, but also tends to bring about a compromise which results in the most satisfactory and economical construction.

It is unusual for an engineer to make such exhaustive studies as those Dr. Waddell presents before preparing the designs for a structure; but, if any justification were needed, it is furnished by the fact that an elevated railroad consists of a few units many times repeated with little if any modification. The cost of the unit is small, but that of the aggregate is very large, hence unduly expensive or faulty details in the unit are of large importance when their repetition is considered.

Dr. Waddell's paper and the discussions upon it will undoubtedly influence greatly if not govern the design of the elevated railroad of the future. Since the paper was written the Boston Elevated Railway and the elevated portion of the New York underground system are the only elevated railroads that have been constructed. The South Side Elevated Railroad Company of Chicago is building an extension to its lines, and elevated roads for

Philadelphia and Pittsburg are under consideration. Dr. Waddell was consulted at the outset regarding the plans for the Boston Elevated Railway; and, though his advice was not strictly followed by the engineers who designed the structure, the impress of his ideas is very evident in the completed road. There can be no doubt that the faulty design and construction which were long since abandoned in railway bridges but which were considered good enough for an elevated road when the earlier New York and Chicago roads were built will never be employed again; for the opinions so forcibly stated by Dr. Waddell and those who discussed his paper make it impossible for any designer to revert to antiquated ideas of design.

The underground railway has recently become prominent among the rapid transit systems of large cities; Boston has a small road which is being extended; the lines in operation, under construction, and under consideration in New York promise to form a system which will permeate every section of the city, and Chicago has begun a vast system; but there will probably be an increase rather than a decrease in the construction of elevated railways. Their first cost is much less than that of the underground railway, hence, notwithstanding their many objectionable qualities, their construction and operation will be profitable where the cost of the underground system would be prohibitive. Present systems will be extended and renewed. and new lines will be built as our smaller cities grow and demand transit facilities superior to those of the surface lines; hence every influence which tends to increase the strength, safety, appearance, and economy of the roads of the future is of large importance. Dr. Waddell's paper is the most important work written on this subject, consequently no apology is necessary for reproducing it and the discussions and thus making them more generally available.

AMERICAN SOCIETY OF CIVIL ENGINEERS.
INSTITUTED 1852.

TRANSACTIONS.

No. 806.

A STUDY IN THE DESIGNING AND CONSTRUCTION OF ELEVATED RAILROADS, WITH SPECIAL REFERENCE TO THE NORTHWESTERN ELEVATED RAILROAD AND THE UNION LOOP ELEVATED RAILROAD OF CHICAGO, ILL.

By J. A. L. Waddell, M. Am. Soc. C. E.

Presented February 17th, 1897.

WITH DISCUSSION.

The principal object of this paper is to bring out an exhaustive discussion on the subject of the designing and construction of elevated railroads.

For some years the author had felt that the methods in vogue for constructing elevated railroads were radically wrong, hence, when he assumed the duties of Consulting Engineer to the Northwestern and Lake Street Elevated Railroads, in July, 1894, he began an elaborate investigation concerning the best way to design, manufacture, and build such structures. In reporting on some proposed plans for the Wabash Avenue Extension of the Lake Street line, which forms one side of the Union Elevated Loop Railway, he gave the following list of essentials of elevated railroad construction:

First. Loads.—The loads to be considered are these:

A. Live load.

B. Dead load.

C. Thrust of braked trains, or traction load.

D. Wind load, or in reality an assumed transverse load to provide for sway of trains.

E. Centrifugal loads on curves.

Second.—Designing.

F. Longitudinal girders should have sufficient sectional areas, and should be properly detailed.

G. A proper system of bracing between contiguous longitudinal girders should be provided.

H. There should be a proper connection of longitudinal girders to cross-girders.

I. There should be adequate means of transmitting the thrust of braked trains from longitudinal girders to columns without overstraining the cross-girders.

J. The cross girders should be properly designed in respect to both sectional areas and details.

K. There should be a proper connection of cross girders to columns to provide for transmission of both longitudinal and transverse horizontal loads.

L. The sections of the columns should be properly designed to provide sufficient strength to resist direct load, bending from longitudinal thrust, bending from transverse thrust, and, on curves, bending from centrifugal loads.

M. There should be a proper anchorage at the foot of each column to make the latter, as far as strength and rigidity are concerned, absolutely continuous with the pedestal.

N. There should be an adequate wooden floor, effectively attached to the metal-work of the superstructure.

O. The general construction of the entire structure should be as economical as practicable in respect to both quantities of materials and facility in erection, due respect being paid to the more important requirements affecting strength and rigidity.

P. The æsthetics of the design should be considered as much as possible without involving extravagant expenditure therefor.

This list of requirements will be referred to later in commenting upon the details of existing American elevated railroads.

The immediate prosecution of the Lake Street Elevated work was a fortunate circumstance, as far as the investigations for the Northwestern Elevated were concerned, for it gave the author an opportunity, which he might otherwise not have had, to make certain experiments and researches, notably in relation to the bearing capacity of Chicago soil, the details of structures occupying streets, and cold-pressed threads for bolts.

In these investigations the author has received valuable assistance from Charles V. Weston, Esq., who holds the position of Chief Engineer on the Northwestern Elevated, the Union Loop, and the Lake Street Elevated Railroads, and from Samuel M. Rowe, M. Am. Soc. C. E., who was retained temporarily to aid in the preliminary work.

The design of the Wabash Avenue Extension will be referred to later on; meanwhile the investigations for the Northwestern Elevated will be taken up in their consecutive order.

Before proceeding with these, however, it will be well to give a short description of the road. It starts as a double-track structure from the Wabash Avenue Extension of the Lake Street Elevated at the corner of Fifth Avenue and Lake Street, runs north across the Wells Street Bridge to Michigan Street, thence west to Franklin Street; thence north to Chicago Avenue, where it expands into a four-track structure (leaving the street and running into private property), whence it continues in a northerly and westerly direction to a point on Wilson Avenue between Evanston Avenue and the Chicago, Milwaukee, and St. Paul Railway tracks, making the total length of line a little more than 6½ miles, of which all but 1 mile is four-track structure.

I.—MEDIUM STEEL *versus* SOFT STEEL.

At the outset it was necessary to determine whether it is more economical to use unreamed soft steel at a low intensity of working stress, or reamed medium steel at a higher intensity. This question was quickly settled in favor of the medium steel, which can be strained legitimately 10 per cent. higher than the soft steel, and costs practically the same per pound at the rolling mills. The ratio of weights of structure for designs in medium steel and soft steel is about as 93 is to 100, a saving of 7 per cent. in weight of metal in favor of the medium steel. Assuming the price of metal erected to be 3 cents per pound makes the saving in pound price 0.21 cent, while the cost of sub-punching and reaming varies from 0.1 to 0.2 cent per pound, according to the facilities of the bridge shop for doing such work. At present perhaps there is a slight difference in the pound prices erected of soft and medium steel in favor of the former, enough possibly to offset the net saving by reduced weight of the latter, so that, as far as the total cost is concerned, it is immaterial whether unreamed soft steel or reamed medium steel be adopted.

There is another point involved here, however, which is of far greater import than mere economy in cost of erected metal, viz., the proper matching of rivet holes in the component parts of built members. For several years the author has favored the sub-punching and reaming of all metal (although he has not always insisted upon it) not so much for the sake of the somewhat disputed benefit derived from removal of cracked metal by reaming, as for the greater certainty of obtaining properly matched rivet holes. His late investigations in this line, made by examining the shop work of the various bridge manufacturing companies of this country, both personally and through his assistant engineers and inspectors, confirm him to such an extent in this opinion that he is now prepared to make the following statement and to invite both criticism and denial thereof.

All structural metal-work, whether it be medium steel, soft steel, or even wrought iron, should be punched at least ⅛ in. less and reamed to a diameter $\frac{1}{16}$ in. greater than the diameter of the cold rivet, and there is no bridge shop in existence which can turn out truly first-class work without sub-punching and reaming or drilling.

Even when the greatest care is taken in punching the metal of the component pieces of long members, many of the rivet holes will fail to match by as much as ⅛ in., and the author has within a year or two seen ⅞ in. rivet holes elongated to 1¼ in., merely to admit the rivets. Where several component pieces containing badly matched rivet holes are placed together and a tapered flexible reamer is used to enlarge the hole sufficiently to admit the rivet, the latter cannot possibly fill completely the irregular hole, and, therefore, if left in the piece, cannot act effectively. If condemned by the inspector on account of looseness, and then driven out, it will, on account of its crookedness, materially injure the metal about the hole and thus weaken the structure, perhaps doing more damage than it would to leave in the loose rivet.

The use of a tapered, flexibly connected reamer is all humbug, and is not true reaming at all, but merely a means of making it practicable to get the rivets through badly punched holes that assemble irregularly.

Real reaming can only be done with rigid reamers or drills that remain at all times at right angles to the surface reamed, and cut a cylindrical instead of a tapered hole. Such reamers are the only ones that ought to be employed on first-class metalwork, excepting, of course, in confined spaces where they cannot be used, and where the flexibly connected reamer must of necessity be employed.

The author knows well that these opinions are at variance with those of a majority of the manufacturers of structural steel, and it is on this account that he presents them so forcibly. That many manufacturers are opposed to sub-punching and reaming was shown very clearly at the lettings of the contracts for the Wabash Avenue Extension of the Lake Street Elevated, and for the Northwestern Elevated, one manufacturer going so far as to make a difference of one-third of 1 cent per pound between reamed and unreamed work.

At these lettings good evidence was also given confirming a statement of the author, viz.: "It has been hitherto the general opinion that almost any kind of a structure in respect to design, quality of material, and workmanship will suffice for an elevated railroad." One manufacturer remarked to the author in criticism of the plans and specifications submitted to bidders: "Why, your requirements in regard to details and workmanship are as rigid as if you were about to build a railroad bridge." The reply to this was, "Yes. I consider this structure to be just as important as any railroad bridge every built." And why should it not be just as important? Are not the live loads more continuously applied, and is not the assumed maximum load very nearly reached many times per day? On these accounts, is it not even more important to make an elevated railroad absolutely perfect in every detail of design and construction than it is so to make a railroad bridge?

The author is by no means alone in his opinion that nearly all the elevated railroads of this country will, in the not very distant future, have to be replaced, mainly on account of faulty detailing. Of what the faulty detailing consists will be dealt with further on.

At this point the author wishes to call attention to a very reprehensible practice on the part of the bridge companies, which these lettings exemplified quite forcibly, viz., attempting to overthrow the engineer's plans and specifications submitted for tendering. In the case of the Wabash Avenue Extension letting a most determined but unsuccessful effort was made to alter the author's plans, so when the specifications for the Northwestern Elevated were drawn, the following clause was inserted with the permission of the president of the company:

> " All work herein outlined is to be done in strict accordance with the following specifications, the accompanying plans, and such instructions as may be given from time to time by the company's engineers. Bidders are hereby warned that they will be held strictly to the spirit of these specifications, and that it will be bad policy for any one to bid with the expectation that concessions will be made after the contract is closed in order that the work may be cheapened; for while the company's engineers desire at all times to aid the contractors in every legitimate manner to do their work expeditiously and economically, at the same time they have given these plans and specifications the most thorough consideration, and know exactly what they need in respect to both design and quality of materials and workmanship. On this account bidders are respectfully requested not to complicate their tenders by putting in alternative bids based on proposed changes in either plans or specifications; because such alternative bids will not be considered."

The result of the insertion of this clause was rather amusing, for attempts were made to overthrow not only the plans but the specifications also. However, but little difficulty was encountered by the engineers in throwing out all alternative bids; and the contract was let to parties who were willing to tender without suggesting changes in the plans and specifications submitted to the bidders.

Another question that came up at these lettings was that of using acid or basic open-hearth steel. Preference was given to the former in the specifications, but such evidence was submitted to the engineers as to convince them that the basic product can be made as satisfactory as the acid, and at a trifle less cost; consequently, it was adopted. Since then, however, the reports of the company's inspectors indicate that the basic steel is not quite so uniform in quality as the acid; and that it may prove advisable in future specifications for basic medium steel to reduce the average ultimate stress limits from 64,000 lbs. to 61,000 lbs. per square inch.

It appears to the author that the general adoption of basic open-hearth steel is fast tending to the employment of soft steel for bridges. As far as short and medium spans are concerned, this is all right, but it is the opposite for long spans, especially for very long ones, where the dead load is the ruling factor in proportioning the members. Perhaps in the near future some alloy of steel, such as nickel steel, can be made cheaply enough to warrant its use for very long span bridges.

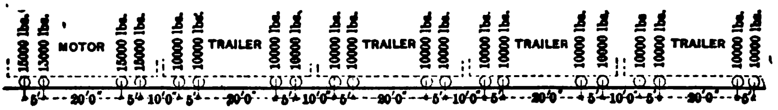


FIG. I.

II.—Weights and Dimensions of Motor Cars and Trailers.

After due deliberation it was decided to make both the motor cars and the trailers 40 ft. long out to out, and to carry each car on four axles, the weight of a loaded motor car being 60,000 lbs., and that of a loaded trailer 40,000 lbs. The distribution of this live load is shown in Fig. 1.

III.—The Best and Cheapest Kind of Portland Cement to Adopt, and the Best Proportions for Concrete Made with Same.

This investigation was made by Samuel M. Rowe, M. Am. Soc. C. E. As a result of it the author has modified his standard specifications for cement so as to read thus:

"All cement used in the work shall be Portland cement of the very best quality obtainable, equal in every particular to the best brands of

American manufacture. It shall be ground so fine that at least ninety-seven (97) per cent. in weight will pass a standard sieve of five thousand (5,000) meshes to the square inch, and so that at least ninety (90) per cent. will pass a standard sieve of ten thousand (10,000) meshes to the square inch.

"When moulded neat into briquettes and exposed three (3) hours, or until set, in air and the remainder of twenty-four (24) hours in water, it shall develop a tensile strength of from one hundred (100) to two hundred and fifty (250) pounds per square inch.

"When moulded neat into briquettes, and after exposure of one (1) day in air, and six (6) days in water, it shall develop a tensile strength of from two hundred and fifty (250) to five hundred (500) pounds per square inch; and after exposure of one (1) day in air, and twenty-seven (27) days in water, it shall develop a tensile strength of from four hundred (400) to six hundred (600) pounds per square inch.

"It shall be an eminently slow-setting cement, must develop its strength gradually, and must show no drop therein. When moulded into pats with thin edges, and either left on glass or not to set in water, the edges must show no signs of checking.

"Briquettes mixed in proportion (by weight) of one (1) part cement to three (3) parts sand, and kept one day in air and the remaining time in water, shall show a tensile strength of from one hundred (100) to one hundred and fifty (150) pounds per square inch after seven (7) days, and from one hundred and fifty (150) to two hundred and fifty (250) pounds per square inch after twenty-eight (28) days.

"In any case the cement adopted must be first approved by the Chief Engineer."

The proportions of Empire or Aalborg cements, which were the brands adopted for the Northwestern Elevated Railroad pedestals, used in making concrete, are:

One part by volume of cement.
Three parts by volume of sand.
Six parts by volume of graded broken stone.

Unless the stone be of several graded dimensions, so as to reduce the proportion of voids to a minimum, its proportion in the concrete should be reduced to five; for while these brands of cement will stand a three-to-one dose of sand, the resulting mortar will not fill completely all the voids in the stone at one, three and six, unless the grading of the stone be done very carefully, and unless the various sizes of stone be thoroughly mixed.

For concrete for bridge pier caissons, using these brands of cement, the author would recommend the following proportions:

One part by volume of cement.
Three parts by volume of sand.
Five parts by volume of broken stone.

In case, however, the concrete be deposited under water or in places where special strength and solidity are required, the proportions should be changed to one, two, and four.

IV.—The Best and Cheapest Kind of Metal Paint to Adopt.

Mr. Rowe conducted this investigation also, but, unfortunately, was not able to complete his experiments. He has promised to give in his discussion his results as far as they go. It was decided to use for the Wabash Avenue Extension Eureka paint, and the National Paint Company's No. 31 for the Northwestern Elevated. In another structure, if the author could have his own way in respect to paint, he would give the metal a good coat of boiled linseed oil at the mills before it is exposed to the weather, one priming coat of Eureka paint at the shops while the metalwork is still under shelter, and two coats of first-class iron oxide paint after erection.

V.—Prices of Timber F. O. B. Cars Chicago.

This investigation was made in order to determine what kind of timber to adopt, and whether it be advisable to specify all heart or a certain portion of sap, the result being that it was decided to use the best quality of long-leaf southern yellow pine entirely free from sap. This question of timber will be further treated in Section 12.

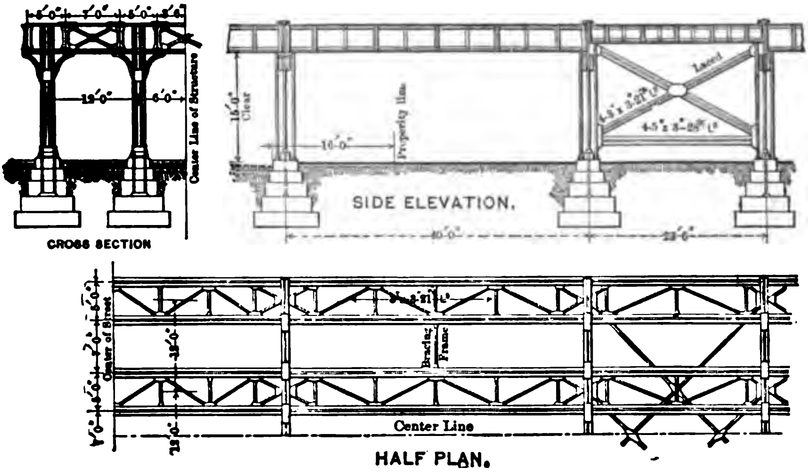
VI.—Best and Most Economical Span Lengths.

This question was investigated very exhaustively, considering every item of expense, including not only the cost of metal in place, but also that of concrete, excavation, back-filling, and pavement; also the possibility of expense for the moving of water pipes and other conduits. The investigation showed that for plate-girder construction through private property the economic span length is about 40 ft., while for construction in the street it varies from 47 to 50 ft., or even 3 or 4 ft. more in case of cross girders spanning wide streets from curb to curb.

The theory of true economy in elevated railroad designing, as far as length of bays is concerned, is simply this: "The cost of the longitudinal girders should be, as nearly as may be, equal to the cost of the bents and their supporting pedestals. In case of doubt adopt the longer span."

VII.—Four-Column *versus* Two-Column Structures.

Detailed estimates of cost show that as far as economy is concerned there is but little, if any, difference between these two styles of bent. Whether the total cost of the four-column bent will exceed that of the two-column one for a four-track structure depends upon the various schedule prices for metal, concrete, excavation, paving, etc., as well as upon the character of the soil. As there is no great difference in the cost of these two types of structure, and as the four-column bent is decidedly the more rigid of the two, it was adopted wherever practicable. Fig. 2 gives a general elevation and plan showing the steelwork. Cantilevering an entire train load beyond the exterior column of a two-column bent is not conducive to rigidity, but this is the only method that will bring the cost as low as that of the four-column bent.


CROSS SECTION

SIDE ELEVATION.

HALF PLAN.

FIG. 2.

VIII.—Braced Towers *versus* Solitary Columns.

Where an elevated railroad occupies private property and crosses the streets by spanning from curb to curb, it is practicable to use braced towers and thus stiffen the structure and check vibration; and, moreover, this arrangement is very economical.

For the Northwestern Elevated, upon which it is proposed to run trains at a speed of 40 miles per hour on the inner tracks between the intertrack stations, which are situated about a mile apart, the consideration of the extra rigidity afforded by the braced towers is quite important. It was therefore decided to use both longitudinal and transverse sway bracing forming braced towers spaced about 150 ft. apart (or two towers per block) and to use the transverse sway bracing on all bents on curves, wherever practicable. Fig. 3 gives the details of the longitudinal sway bracing for a 23½-ft. span.

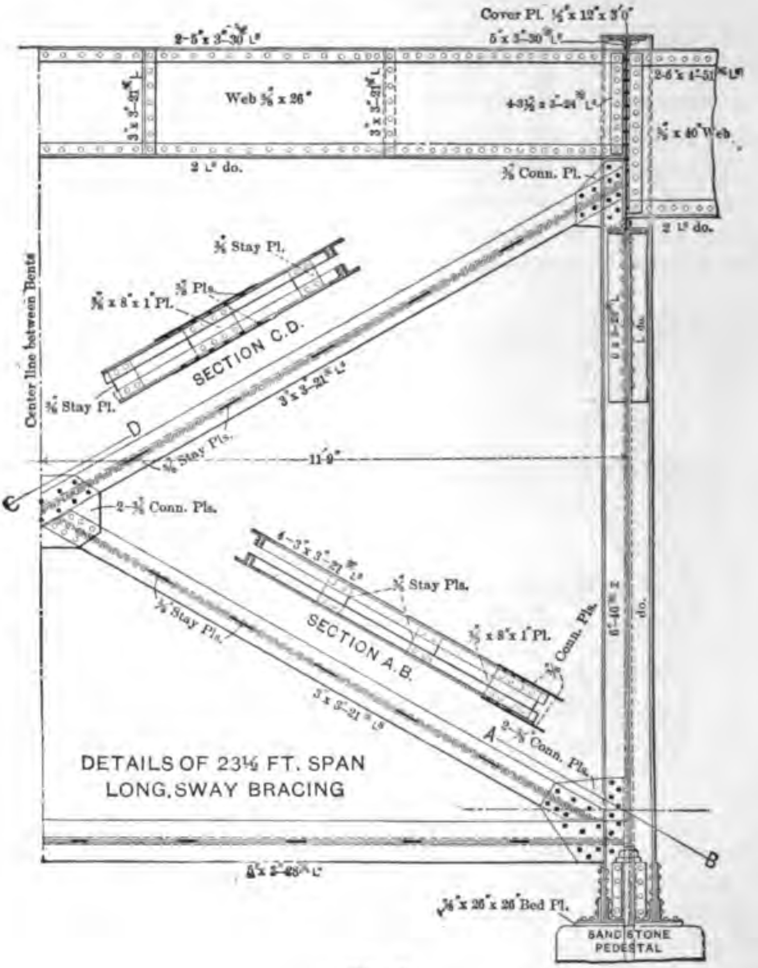


FIG. 3.

Two only of the three spaces between columns are to have transverse sway bracing, thus leaving a longitudinal passage-way for wagons at the center of the structure.

The saving in weight of metal per lineal foot of four-track structure on tangents by adopting braced towers instead of solitary columns was found to be about 140 lbs., or nearly 9 per cent. of the total weight.

IX.—The Best Weight and Dimensions of Track Rails.

After thorough investigation it was decided to adopt, as the best and most economical section, an 80-lb. rail, 5 ins. high, with vertical sides, and containing 45 per cent. of its metal in the head.

X.—Best Arrangement and Dimensions of the Wooden Floor.

The result of the investigation on this subject was, for longitudinal girders spaced 5 ft. centers, the adoption of 6 x 8-in. ties laid flat and spaced 14 ins. centers; 6 x 6-in. inner guards and 6 x 8-in. outer guards on edge, all guards being fastened by soft steel bolts with pressed threads, and connections to the metalwork being made by means of hook-bolts. Fig. 4 illustrates the track system.

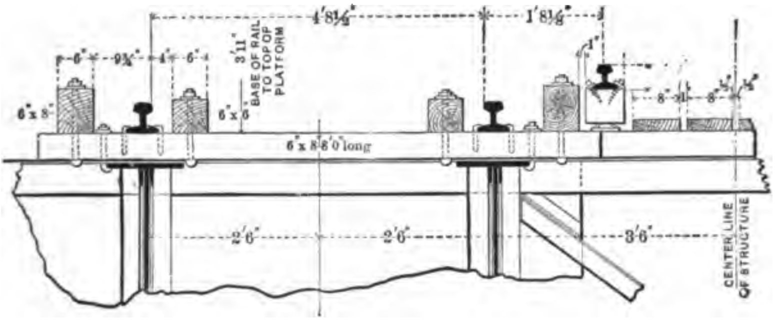


FIG. 4.

XI.—Collection of Data of Various Kinds Concerning Elevated Railroads.

The results of this investigation, made by the author and his assistants by examining the principal elevated roads of the East and those then in operation in Chicago, as far as the designing of the metalwork is concerned, amount simply to the accumulation of a great mass of information exemplifying "how not to do it."

Such negative data are, of course, useful; but, if a properly designed and constructed road in operation could have been examined, the information accumulated would have proved much more valuable.

Much useful information, however, was obtained upon such matters as track, stations, signals, etc., by the examination of existing elevate railroads.

XII.—TREATED *versus* UNTREATED TIMBER FOR TRACKS AND PLATFORMS.

After considerable investigation it was decided to preserve the timber by the vulcanizing process. The following extracts from the author's report to the company on this subject may be of interest.

"Unfortunately, the only vulcanizing works in this country are located in New York City; consequently, the freight rates on vulcanized timber delivered at Chicago are high, the average price for such timber as we need being about $32 per thousand delivered at site, while the untreated timber would cost only $18 per thousand. It will cost about $6 per thousand additional to put the timber in place.

"Vulcanized timber has been used on the New York Elevated Railroads for twelve years without showing any signs of material deterioration, and the chances are that it will last fully twenty-five years.

"Our investigations lead us to the conclusion that it costs about $1 per tie to replace ties in the track without interfering with the traffic, over and above the value of the tie itself; while for new work the cost of laying a tie is only 20 cents, making a difference of 80 cents.

"For the purpose of comparison let us take a mile of double track. The bill of timber therefor is as follows:

Ties	9 052:	6 ins.	x 8 ins.	x 8 ft....	289 664 ft.
Guards	920:	6 "	x 8 "	x 24 "	88 320 "
Guards	920:	8 "	x 8 "	x 24 "	117 760 "
Planks	5:	2 "	x 8 "	x 5 280 "	35 200 "
Joists	1 508:	4 "	x 8 "	x 8 "	32 171 "
					563 115 ft.
					Say 564 M.

"In order to be absolutely on the side of safety, let us assume the life of the vulcanized timber to be only fifteen years, or just twice that of the untreated timber, and that the excess of cost of replacing ties during traffic over that when there is no traffic is 60 cents instead of 80 cents per tie. The rate of compound interest assumed is 5 per cent. At the end of fifteen years, then, according to these assumptions, the floor in either case would have to be renewed, and the total costs for the fifteen years would be as follows:

FOR VULCANIZED TIMBER.

564 M at $38	$21 432.00
Compound interest on $21 432 for 15 years....	23 125.13
Total	$44 557.13

FOR UNTREATED TIMBER.

564 M at $24	$13 536.00
564 M at $24	13 536.00
9 052 ties at 60 cents	5 431.20
Compound interest on $13 536 for 15 years	14 605.30
Compound interest on $18 967 for 7½ years	8 383.50
Total	$55 492.00

" According to these figures the untreated timber is about 25 per cent. more expensive than the vulcanized timber, even upon assumptions that are manifestly unfavorable to the latter."

XIII.—BEST AND CHEAPEST MATERIAL FOR PEDESTAL CAPS.

Estimates of cost were made on several types of pedestal caps, including castings like those used on the Metropolitan Elevated, Kettle River sandstone blocks, and granitoid; and the last was adopted because it was considered both the cheapest and best. Experience with the finished pedestals has given the company's engineers no reason to regret their decision concerning this matter. The granitoid covering for the concrete of the pedestals is 6 ins. thick, and is composed of one part of Portland cement, two parts of fine granite screenings and four parts crushed granite, no piece being too large to pass through a ring ¾ in. in diameter, the top surface being made extremely smooth, to exact elevation, and perfectly level.

XIV.—BEARING CAPACITY OF CHICAGO SOIL.

Mr. Rowe made a number of experiments on the bearing capacity of Chicago soil, using an apparatus designed by the author, by which a load of pig iron was applied centrally to a square block of timber. As Mr. Rowe has promised to treat this subject in his discussion, no further details will be given here, except to state that the safe load in some places ran as low as 1 ton per square foot.

XV.—BEST STYLE OF ANCHORAGE FOR COLUMNS.

Where longitudinal sway bracing is employed, two anchor bolts per pedestal were used; but, where reliance was placed on the transverse strength of the column to resist the bending effects of longitudinal and transverse thrusts, four anchor bolts per pedestal were employed. All the anchor bolts of each pedestal were passed through a single anchor-casting or spider embedded in the concrete and set very carefully to exact line and level. The details of the foundation are shown in Fig. 5. The upper ends of the anchor bolts are enclosed loosely with a curved steel plate, long enough to contain an ample number of rivets for attaching to the column, and having a square and smooth top to receive a heavy steel washer plate. As there are enough rivets connecting the curved plate to take care of both the direct and the secondary or induced stresses due to eccentricity, this entire pedestal detail is such as to make the column and the pedestal absolutely continuous, so that they act as a unit in resisting overturning; hence all calculations of strength of parts were made upon the assumption that the foot of the column is fixed.

A detail similar to this was employed by the author in 1891 when designing the columns and pedestals of the Sioux City train-shed; and,

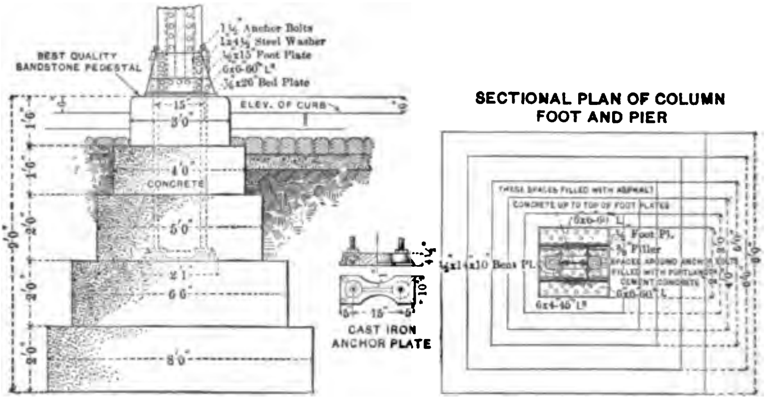


FIG. 5.

as far as he knows, this was the first time that a column-foot detail involving a truly fixed end for the column was ever used.

The ordinary method of running the anchor bolts through the horizontal foot-plate of the column near its edges or corners does not make a fixed-end column—far from it, as a few simple calculations will show.

XVI.—Plate Girders *versus* Open-Webbed Girders.

In designing these elevated railroads for Chicago, many estimates have been made for both plate-girders and open-webbed girders, which demonstrate that there is practically no difference in the weight when both girders are properly designed. As the open-webbed girders cost a trifle more per pound to manufacture, there is no economy in their use; nevertheless they were adopted for all structures running longitudinally in the streets in order to comply with certain city ordinances.

The observance of these ordinances was sometimes carried to extremes, producing ridiculous combinations of solid and open web in the same girder, and an evident waste of material and labor. For this the engineers are not to blame, because they did not frame the ordinances.

XVII.—CRIMPING OF WEB-STIFFENING ANGLES *versus* THE USE OF FILLING PLATES.

An investigation of this question was made by writing to a number of the leading bridge companies, and propounding to them this query: "If you had a lump sum contract for building a bridge, would you find it more economical to use crimped angles for web stiffeners, or to adopt plain angles with fillers beneath them?" Some replies favored crimping and some did not; but the majority, including most of the larger companies, considered crimping a little the more economical, especially for intermediate stiffeners; consequently on the Chicago work all intermediate stiffeners are crimped and all end stiffeners have filling plates.

XVIII.—BEST SECTIONS FOR COLUMNS.

Investigation concerning strength, capacity to resist impact, facility of erection, economy of metal, etc., determined that the section for columns located in the street should be two 15-in. rolled channels with the flanges turned inward and a 15-in. rolled **I**-beam riveted between to act as a central web or diaphragm, the flanges of the channels being held in place by interior stay plates spaced about 3 ft. centers. In most cases the column feet pass below the pavement and are embedded in the concrete, to which, of course, they are bolted, but in some cases they rest on pedestals a little above the level of the sidewalk. The main object in turning the flanges inward is to enable the column better to resist impact from heavily loaded vehicles. Just above the pavement there is a curved casting filled with concrete and surrounding the column to act as a fender.

This column is very satisfactory after it is erected, although it gives some little difficulty in the shops and involves a little more field riveting than usual. One complaint made was that the planes of the top and bottom flanges of **I**-beams are never exactly parallel to each other, hence some straightening was necessitated.

For columns located on private property or on sidewalks where the structure is transverse to the street, four **Z**-bars and a web plate were adopted as the most satisfactory section. At the top of the column a wide curved web plate and curved angles are used. This design makes a most satisfactory column, which goes through the shops readily, and which is well adapted for quick erection. It is true that it necessitated a special tool for cutting the webs to a circular curve, but after this was made, the manufacture was easy and comparatively inexpensive. The Union Bridge Company, of Athens, Pa., and the Elmira Bridge Company, of Elmira, N. Y., together took the contract for the metal-work of the entire Northwestern Elevated and the Fifth Avenue side of the Union Loop. The Lake Street side of the Loop was built by the Phœnix Bridge Company, of Phœnixville, Pa., and the other two sides are being built by the Pencoyd Iron Works, of Pencoyd, Pa.

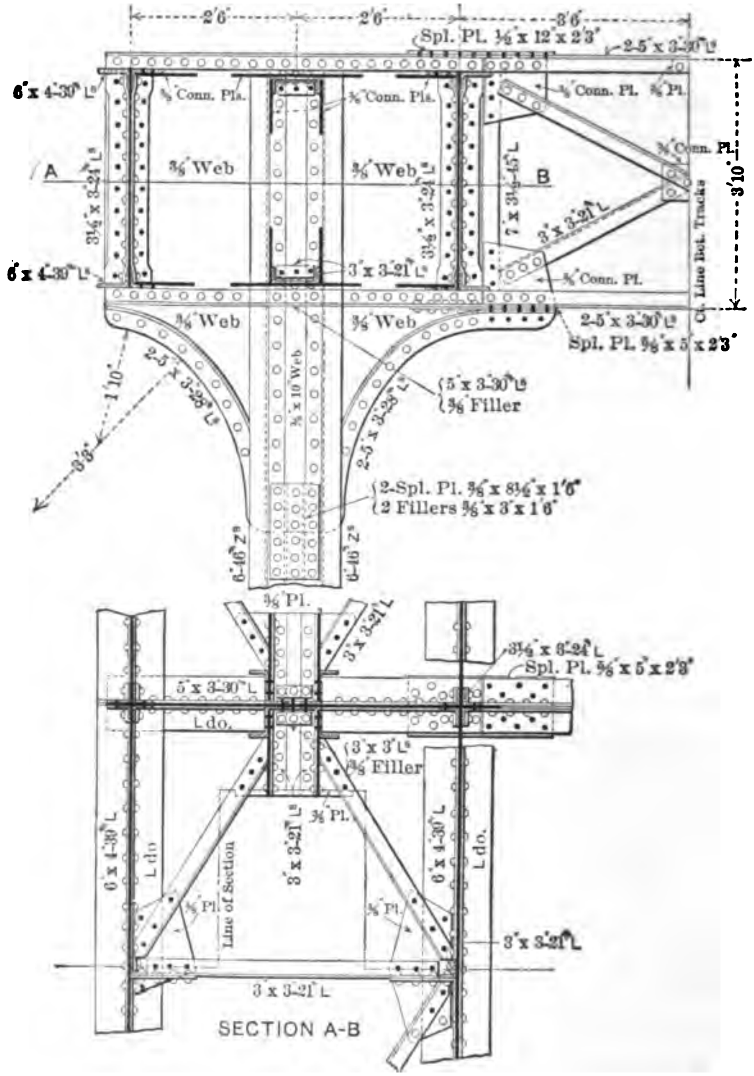


FIG. 6.

Figs. 6 and 7 illustrate features of the column construction, the latter figure also showing the details of an expansion joint.

XIX.—Best Style of Expansion Joint.

The designing of a perfectly satisfactory expansion joint is no simple problem; consequently, it demanded considerable study, the result of which was the adoption of the pocket shown in Figs. 8 and 9 to receive the loose end of a longitudinal girder. The most important feature of this design is that the center of pressure from the longitudinal girder is distant from the cross girder about half the length of the pocket, which reduces the moment due to eccentricity upon the group of rivets connecting the pocket to the cross-girder, and prevents the bearing of the longitudinal girder from coming on an edge of metal, as would be the case were not the center of pressure thrown toward the cross-girder by the small base plate. Again, the number of rivets connecting

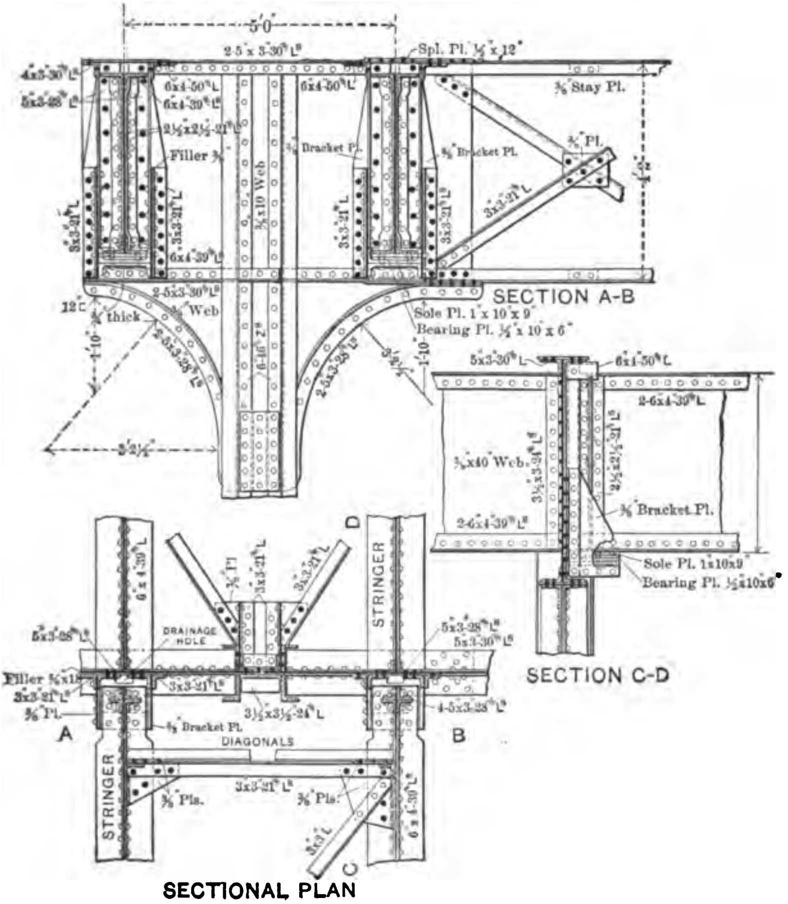


FIG. 7.

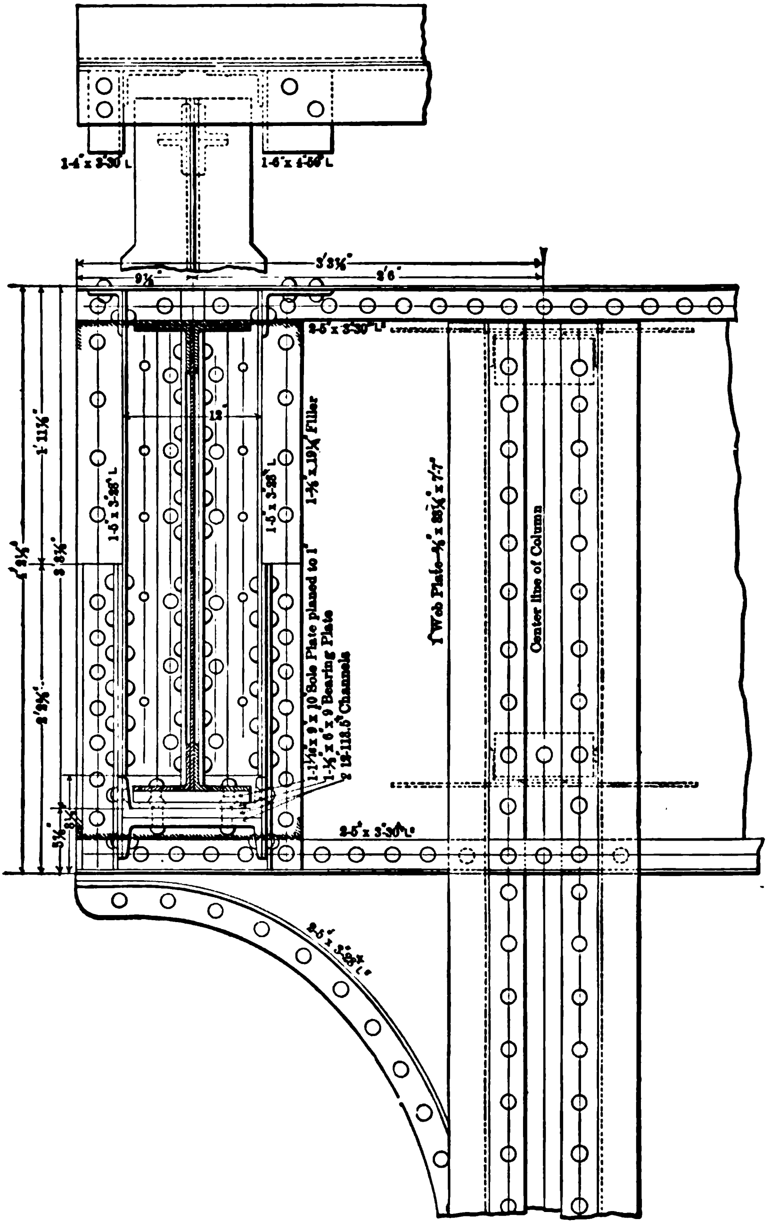

1-4" x 3-30 L
1-6" x 4-56" L
3' 3⅜"
9¼"
2' 6"
2-5" x 3-30" L'
12"
1' 11⅛"
3' 3⅛"
4' 2½"
2' 2⅝"
5⅛"
3½"
1-5" x 3-28" L
1-5" x 3-28" L
1-⅝" x 19¼" Filler
1-1½" x 9 x 10 Sole Plate planed to 1"
1-⅞" x 6" x 9 Bearing Plate
2 15-118.5" Channels
1" Web Plate-⅜" x 88¼" x 7-7"
Center line of Column
2-5" x 3-30" L'
2-5" x 3-28" L'

FIG. 8.

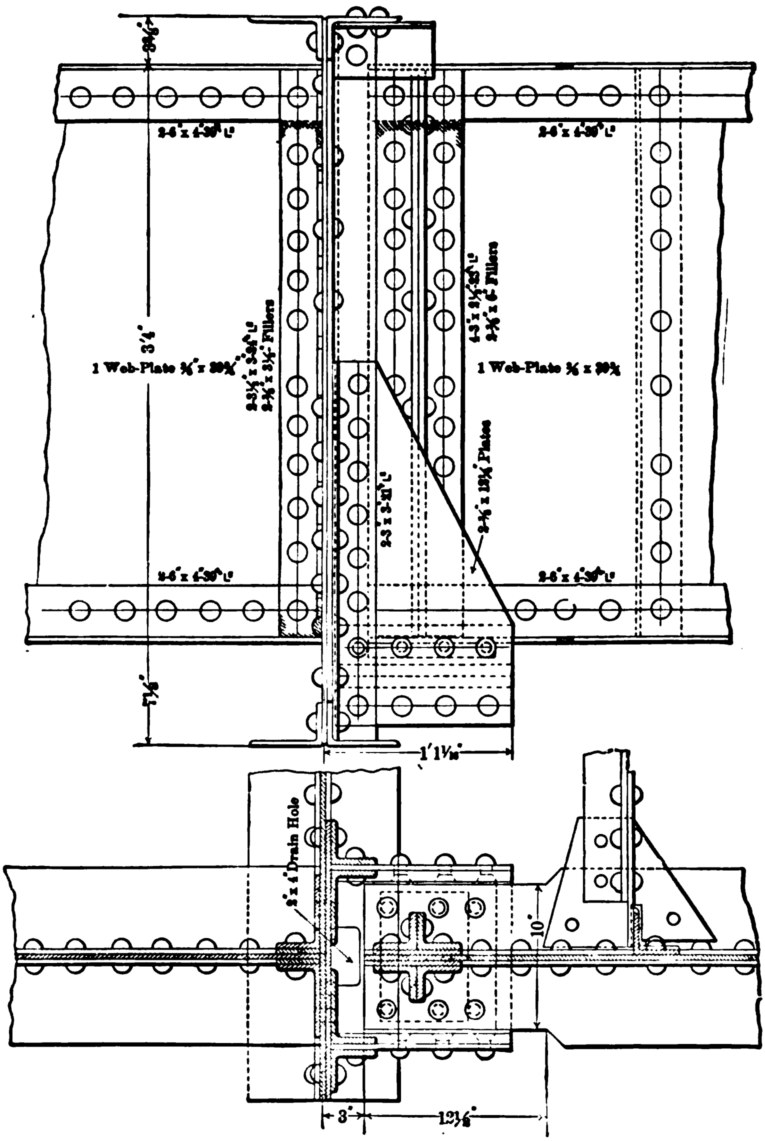

3 3/8"
2-6" x 4-30" L's
2-6" x 4-30" L's
3'4"
1 Web-Plate 3/8" x 39 3/4"
2-3 1/2" x 3-5 1/4" L's
2-3/8" x 3 1/2" Fillers
4-3" x 3 1/2" x 25" L's
2-3/8" x 6" Fillers
1 Web-Plate 3/8 x 39 3/4
2-3/8" x 13 1/4" Plates
2-3" x 3-11" L's
2-6" x 4-30" L's
2-6" x 4-30" L's
7 1/8"
1'1 1/16"
8" x 4" Drain Hole
10"
3"
12 3/8"

FIG. 9.

the pocket to the cross-girder is ample for both the direct shear and the secondary stresses due to the moment caused by the eccentric bearing. The longitudinal girder fits laterally in the pocket, and its top is held between angle clips riveted to the cross-girder. Thus the expansion ends of the longitudinal girders are held laterally to the cross-girders just about as rigidly as are the riveted fixed ends.

The detailing of the entire expansion end is so arranged that all parts of the metal-work are accessible to the brush for painting, although extra care will have to be used by the painter on this portion of the structure, in order to make sure that no portion of the surface is unprotected.

XX.—STYLE OF BRACING ON CURVES.

The extra bracing on curves is composed of two lower lateral systems, each pertaining to two tracks, and consisting of a double system of cancellation, the diagonals being formed of two 4 x 3-in. angles riveted together and to the lower flanges of the longitudinal girders where they cross the same. The columns on curves are made larger and stronger than those on tangents, in order to resist properly the centrifugal loads.

XXI.—PROPER LIMIT OF LENGTH OF STRUCTURE BETWEEN EXPANSION JOINTS.

This question involves the effects of changes of temperature, more especially in producing bending on the columns. The latter were figured for deflection with due regard to the fixedness of their ends, which increases the extreme fiber stresses due to changes of temperature. The investigation showed that 150 ft. should be the ordinary limiting distance between expansion points. On almost the entire lines of the Northwestern and Loop this limit was observed; but in two or three cases, owing to peculiar local conditions, it had to be exceeded. In these cases, however, the columns most affected were strengthened.

XXII.—TRACK-BOLT NUTS ABOVE *versus* TRACK-BOLT NUTS BELOW.

Each method has both good and bad features. With nuts below, the hole through the wood can readily be protected from the entrance of water, but the nuts may work off the bolts without notice being taken of the fact by the track-walker. With nuts above, any loosening of the bolts would be seen at once, but a water-tight joint is hard to make. The latter arrangement, after much discussion, was adopted, and cup-shaped washers let into the wood were employed. A liberal use of paint in these cups will probably seal them against percolation of water, but their insertion in the wood seems like an invitation for rot. An important advantage in using these cups is that there are no projecting nuts above the wood to trip anyone walking over the track.

XXIII.—SUPERELEVATION ON CURVES.

It was decided not to attempt to obtain this by elevating or depressing the longitudinal girders, or by using wooden shims on outer girders, but to employ wedge-shaped ties. Three bevels only are used on the line, viz., 1, 2 and 3 ins. in 5 ft. Such bevels, it is true, will not afford the theoretical superelevation required for the maximum speed on sharp curves; but it was considered that this maximum speed could not be maintained on sharp curves, hence the compromise between theory and practice. Experience in operation alone will tell whether the decision of the company's engineers in this matter is correct.

XXIV.—BEST STYLES OF STATIONS.

For stations on the company's private property it was decided to adopt a single brick house to accommodate the entering passengers for all four tracks, the exit passengers leaving the platforms by special exit stairways leading to or near the street, each of the said stairways being provided at its foot with a turnstile prohibiting entrance but permitting exit. This arrangement dispenses with several platform employees and prevents the station house and stairways from obstruction by passengers moving in opposite directions.

At first it was intended to run the exit stairway at right angles to the line and land on the sidewalks of the cross streets, as shown in Fig. 10, but it was found afterward that this method would in some cases involve the payment of unduly high damages to property-owners, hence it was decided to confine these stairways entirely to the company's property, as in Fig. 11. From the operating point of view the first design is the better one in that it does not cut up the already somewhat narrow platforms with apertures for exit, as does the design adopted. However, the pressure of the financial department was too strong for the engineers; consequently, the proposed change was adopted.

The following extracts from the specifications for stations on the Northwestern Elevated, together with occasional reference to Figs. 10 and 11, will give a fairly clear idea of what these stations will be like when completed.

"There are two slightly different styles of stations on the line, viz.: 'Interior Track Stations' and 'Exterior Track Stations,' the former being placed at intervals of about one mile, and the latter at intervals of about a quarter of a mile.

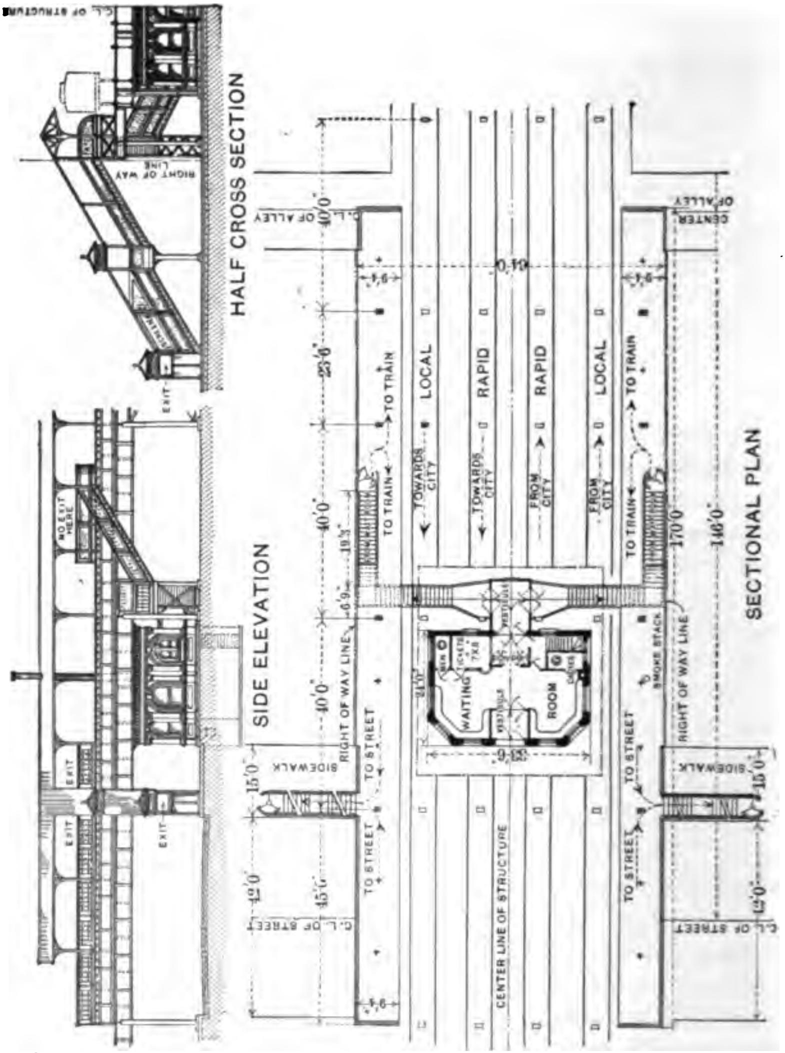

HALF CROSS SECTION
C.L. OF STRUCTURE
RIGHT OF WAY LINE
EXIT
NO EXIT HERE
SIDE ELEVATION
SECTIONAL PLAN
LOCAL
RAPID
RAPID
LOCAL
TOWARDS CITY
TOWARDS CITY
FROM CITY
FROM CITY
TO TRAIN
TO STREET
WAITING
ROOM
MEN
TICKETS
VESTIBULE
LADIES
SIDEWALK
SMOKE STACK
RIGHT OF WAY LINE
CENTER LINE OF STRUCTURE
C.L. OF STREET
C.L. OF ALLEY
CENTER OF ALLEY
40'0"
25'0"
40'0"
40'0"
15'0"
42'0"
45'0"
170'0"
146'0"
19'3"
6'9"
4'6"

FIG. 10.

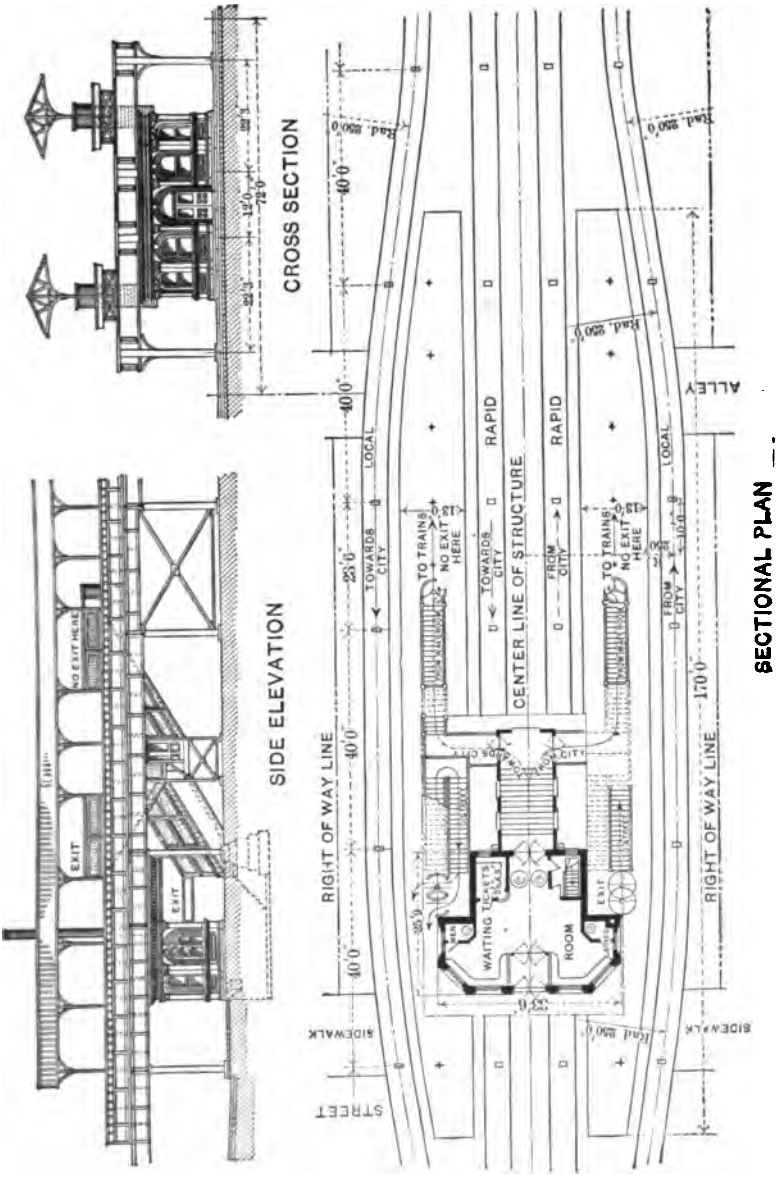

CROSS SECTION
22'3"
12'0"
22'3"
72'0"
SIDE ELEVATION
NO EXIT HERE
EXIT
EXIT
SECTIONAL PLAN
RIGHT OF WAY LINE
RIGHT OF WAY LINE
CENTER LINE OF STRUCTURE
LOCAL
LOCAL
RAPID
RAPID
TOWARDS CITY
TOWARDS CITY
FROM CITY
FROM CITY
TO TRAINS
NO EXIT HERE
TO TRAINS
NO EXIT HERE
WAITING ROOM
TICKETS
MEN
LADIES
EXIT
TOWARDS CITY
FROM CITY
ALLEY
SIDEWALK
SIDEWALK
STREET
Rad. 250'0"
Rad. 250'0"
Rad. 250'0"
Rad. 250'0"
40'0"
40'0"
40'0"
40'0"
23'6"
13'0"
13'0"
10'0"
25'0"
33'6"
170'0"

FIG. II.

"The essential points of difference in the two styles of stations are in the platforms and in the vestibule and stairway leading thereto.

"In the Exterior Track Stations the platforms are outside of the tracks, while in the Interior Track Stations they are between the exterior tracks and those adjacent, the exterior tracks being spread so as to pass around the platforms.

"There will be but one house to each station, passengers entering it from the street, but not passing through it when leaving the line, as special exit stairways leading to the street are provided.

"The houses are to be built as follows: The basement walls are to be composed of rubble, resting on dimension stone footings; the main walls are to be of common brick, faced with pressed brick and terra cotta trimmings; the roof is to be a composition gravel roof; the floors are to be of white oak, resting on common yellow pine flooring over yellow pine joists; and the finish is to be of antique oak. The houses are to be lighted by both electricity and gas, and are to be heated by hot water.

"The ticket office is located on one side of the rear vestibule which leads to the entrance stairways, that in turn lead to the platforms.

"These platforms are to be constructed of transverse and longitudinal timbers with a two-inch (2") vertical-grain yellow pine flooring on top. They are to be sheltered by canopies of corrugated iron supported by steel frame construction.

"Around all stairway openings, along the outside of exterior platforms, and at ends of all platforms are to be gas-pipe hand-railings paneled with grillework screens."

XXV.—Best Method of Heating Stations.

After considerable deliberation and discussion it was decided to heat all stations with hot water. This is undoubtedly the most satisfactory method for houses on the ground; but for the Loop stations and those of the Northwestern which are supported by the metal-work the author would have preferred heating by gas so as to avoid the carrying to and fro of coal and ashes, with the unavoidable accompanying dirt and trouble. The use of gas, though, would have been more expensive than that of coal.

XXVI.—Relative Costs of Double-Track Structure with Columns in the Street and with Columns Just Inside of Curb Lines.

This question was investigated so as to determine whether in certain cases it would be worth while to strive for permission to put the columns in the street. As will be seen in the table given under Section XXVIII, the cost of structure per mile of double track was estimated to be $267,760 with columns inside of curbs, and $240,537 for columns in street, making a difference of $27,223 per mile of double track, or a relative difference of between 11 and 12 per cent.

XXVII.—PRESSED-THREAD BOLTS *versus* CUT-THREAD BOLTS.

As the manufacture of pressed-thread bolts is a patented process, the author first obtained from the patentees a guaranteed pound price for their bolts delivered f. o. b. cars Chicago, at the same time getting corresponding prices for both upset and plain bolts with cut threads. He then had his metal inspectors test to destruction several specimens of pressed-thread bolts so as to determine their strength in comparison with cut-thread bolts.

As the difference in the pound prices was small, and as the strength of the pressed-thread bolts is fully 50 per cent. greater than that of the cut-thread bolts, the comparison resulted greatly in favor of the former, consequently they were adopted for all the anchor bolts and track bolts on both lines of road. The author feels that he cannot speak too highly of these pressed-thread bolts, for the results of the tests were surprising. When it is considered that the cold-pressing process reduces the effective diameter of the soft steel rod at the root of the thread, and in fact increases it but little at the edges, it might be imagined that when the bolt is tested to destruction, it would break in the threaded portion. Such, however, is not the case, for all the specimens broke in the body of the rod, and, strange to say, the threads were so little injured that the nuts could be turned readily over the whole length of same.

XXVIII.—STUDIES INVOLVING A NUMBER OF DESIGNS FOR DIFFERENT STYLES OF STRUCTURE.

The investigations included under this heading are the most elaborate of all those made. They involved careful designs and estimates of cost of the following types of structure, all of which are shown in cross-section in Figs. 12 to 24 inclusive.

Design 1. Four-track structure with longitudinal bracing, supported by four **Z**-bar columns, the cantilevers and columns being made in one piece in the shops.

Design 2. Similar to Design 1, except that the cross-girders are riveted to the columns in the field, and the brackets are omitted.

Design 3. Four-track, two-column structure, with longitudinal bracing.

Design 4. Four-track, four-column structure, without longitudinal bracing.

Design 5. Four-track, two-column structure, without longitudinal bracing.

Design 6. Double-track, two-column structure, with longitudinal bracing, similar to Design 1.

Design 7. Double-track, two-column structure, with longitudinal bracing, similar to Design 2.

Design 8. Double-track, two-column structure, with longitudinal bracing, the columns being spaced 17 ft. centers transversely to the structure.

Design 9. Double-track, two-column structure, without longitudinal bracing, similar in construction to Design 4.

Design 10. Four-track, four-column structure, without longitudinal bracing, the columns being flared out at the top and extending only to the plane of the bottoms of stringers, and the column section being composed of two 15-in. **I**-beams.

Design 11. Four-track, four-column structure, similar to Design 10, except that channels are used instead of **I**-beams in the columns.

Design 12. Double-track, two-column structure, without longitudinal bracing, for the alternative route along Fifth Avenue and Franklin Street, the columns being placed on the curbs.

Design 13. Double-track, two-column structure, without longitudinal bracing, also for the alternative route along the streets, the columns in this case being placed in the roadway.

The following is an almost verbatim extract from the author's report, all references to drawings being omitted.

In explaining and discussing each of these designs, the following questions in the order here given will be considered: First, general description; second, strength; third, rigidity; fourth, economy; fifth, æsthetics; sixth, uniformity of construction; seventh, facility of manufacture and erection.

In making these various calculations there has been assumed a typical block 292 ft. long, simply for purpose of comparison. This block, however, is of about the average length of the blocks through which the line will pass.

Design 1, Fig. 12.

Design 1 is a four-track structure which is supported by four **Z**-bar columns.

General Description.—Each track is carried by a column which is located directly beneath its central line. The stringers are spaced 5 ft. apart, and are, therefore, almost directly beneath the rails. They are carried by short cantilevers, one on each side of the column. The web of these two cantilevers and that of the top of the Z-bar column are all in one piece, this web being carried through the top of the column. The top flange of the cantilevers is also continuous over the top of the column, and its web is carried far enough down the column to form a good bracket on each side.

The spans are all to be 40 ft. in length, excepting those over the street, which are 45 ft., and those having longitudinal bracing, which are 23 ft. 6 ins. There will be two such braced spans to each 292-ft. block, and a correspondingly greater number for blocks of greater length. This longitudinal bracing is designed to take up the entire horizontal thrust due to braked trains or to traction, the intermediate columns being designed to carry only the direct load and transverse thrust from wind load.

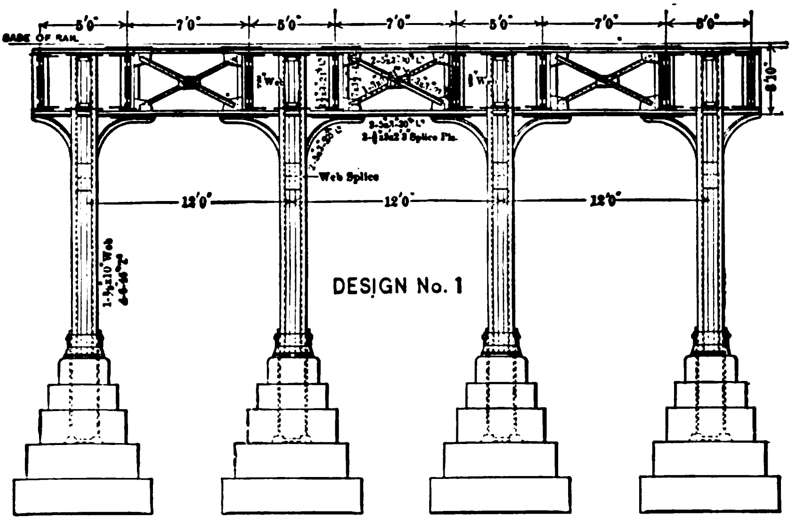


FIG. 12.

The stringers or longitudinal girders are plate girders, riveted solidly to the cantilever brackets, except at the expansion ends. The expansion joints are spaced about 150 ft. apart, and will be similar in design to those used on the Wabash Avenue Extension of the Lake Street Elevated Railroad. The longitudinal thrust due to expansion and contraction of the stringers is carried to the column in each bent by short struts, but the longitudinal thrust due to braked trains is carried by the stringers directly to the longitudinal bracing.

On curves, where permissible, a system of vertical sway bracing will be used, and, where it cannot be employed, the columns will be made strong enough to transmit the transverse thrust to the pedestals.

These pedestals are to be made of concrete, covered with granitoid.

Strength.—Every portion of this structure has been made amply strong to carry the greatest stresses and loads which can come upon it. It would be difficult to make stronger or more efficient columns and cantilevers than the ones used throughout this design; for these columns, cantilevers, and brackets are made in one piece in the shops, and there is not a weak point in them.

The bracing towers, if they may be so termed, are well braced, both longitudinally and transversely in vertical planes, and horizontally at the top, and take care most effectively of the total longitudinal thrust.

Rigidity.—The stringers are thoroughly braced together so as to prevent as much as possible all transverse vibration, and this bracing, together with the longitudinal sway bracing in the towers, prevents any undue longitudinal vibration. As the columns are placed directly beneath the centers of the tracks, there is no possibility of unequal deflection in the transverse girders and cantilevers, such as might occur if the columns were not so placed. All columns are anchored to the pedestals by long anchor bolts which extend well into the concrete and make the column and pedestal act as one piece. Upon the whole this design is so constructed as to make it as rigid a structure as can be obtained.

Economy.—While this structure has been made thoroughly first class in every respect, no material has been wasted in so doing. The spans have been made of the most economical lengths; the spacing of columns transversely to the structure, the sections of columns used, the style of cantilever, and the stringer bracing are all examples of true economy of design, but probably the feature that saves more metal than any other is the use of longitudinal sway bracing in the towers, as will be seen by comparing the weights of Designs 4, 10, and 11, with the one now under consideration. This comparison shows that from 140 lbs. to 165 lbs. of metal per lineal foot of structure have been saved in Design 1, or from $8,000 to $11,000 per mile, and at the same time a more rigid and stronger structure has been evolved than that illustrated in any of the other four-track designs.

From an economic point of view, only one of the designs, viz., Design 3, offers any advantage over Design 1, but there are other considerations which offset this apparent economy in Design 3.

Æsthetics.—This structure is light and airy, and upon the whole presents a very neat appearance; more so, perhaps, than any one of the other designs.

Uniformity of Construction.—The style of construction will be the same throughout, with only very slight alterations at stations and on curves, the double-track structure included. This will not be true of several of the other designs.

Facility of Manufacture and Erection.—The style of column used makes it practicable to do nearly all of the riveting in the shops, the cantilevers and brackets, as before stated, forming a part of the column. As the cross girders have to carry no direct load whatsoever, they are made very light, and are to be connected to the cantilevers in the field, the rivets necessary to make this connection, together with those connecting the stringers to cantilevers and sway bracing, being the only field rivets required.

The work is all plain and straight, excepting the curved brackets. All parts are made of as few pieces as possible, and there are no large or unwieldly members to handle.

This design will be easier to manufacture and erect than any one of the other designs now under consideration.

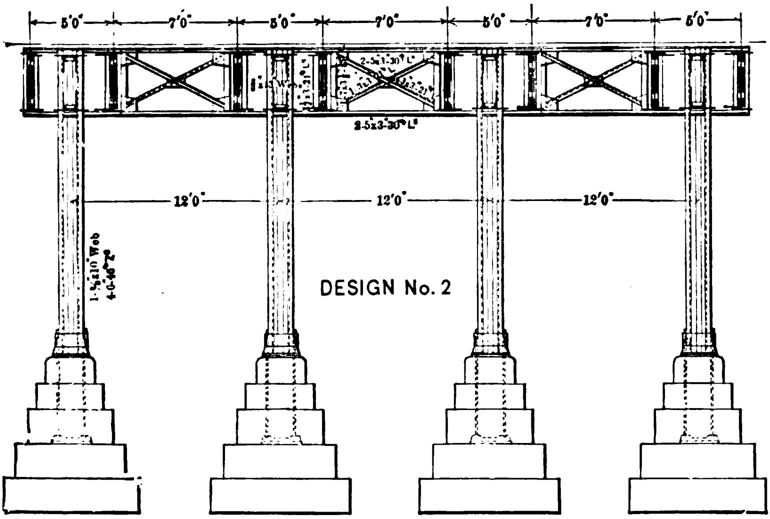


FIG. 13.

Design 2, Fig. 13.

This is similar to Design 1.

Strength.—As far as the strength of the various parts of the structure is concerned, this design is almost the same as Design 1. The same sections are used in the stringers, columns, cross-girders, and transverse and longitudinal bracing.

Rigidity.—This design will not be quite so rigid as Design 1, as there are no brackets beneath the cross-girders, and the method of connecting the cantilevers and cross-girders to the columns is not so good, for in Design 1 the cantilevers and columns are all made in one piece; otherwise, the two designs are identical.

Economy.—The cost of Design 2 is the same as that of Design 1, viz., $65.10 per lineal foot (average), including curves.

Æsthetics.—Owing to the omission of the brackets, this design does not appear so well as does Design 1.

Uniformity of Construction.—What was said of Design 1 applies to Design 2 as well.

Facility of Manufacture and Erection.—In this case the cantilevers and cross girders are riveted to the columns in the field; this necessitates driving more rivets in the field than in case of Design 1, but all the work is plain and straight and will be easy to manufacture and erect.

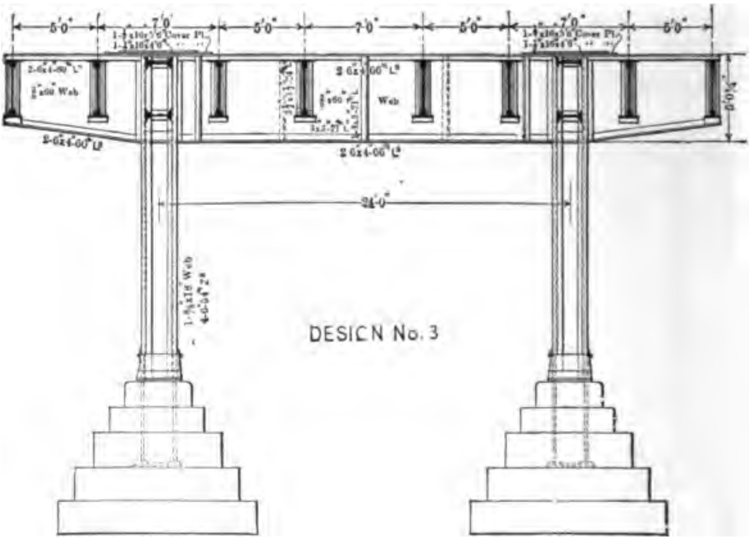


FIG. 14.

Taking it as a whole, this design is not quite so satisfactory as Design 1, and it costs quite as much money.

Design 3, Fig. 14.

Strength.—Design 3, as well as all the others, has been made good and strong in all its details.

Rigidity.—This design is a two-column, four-track structure, with the two outer tracks cantilevered out beyond the columns, which are spaced 24 ft. centers in planes transverse to the direction of the tracks. While the structure has been designed to be as rigid as is possible with this style of construction, the unequal distribution of load and the lengths of cantilever and girder necessary do not insure the rigidity which is obtained in Designs 1 and 2.

Laterally, the structure is well braced; and, longitudinally, the braced towers are used, as in the preceding designs.

Economy.—This design is a trifle cheaper than Designs 1 and 2, on account of the saving in pedestals, the metalwork costing considerably more, though, than in those designs.

Cost of Design 1	$65 10
Cost of Design 3	64 60
Difference	$0 50, or $2,640 per mile.

Æsthetics.—This structure is by no means pleasing in appearance.

Uniformity of Construction.—In this design in changing from four-track to double-track structure, it will be necessary to change entirely the style of construction, which is not the case in Designs 1 and 2.

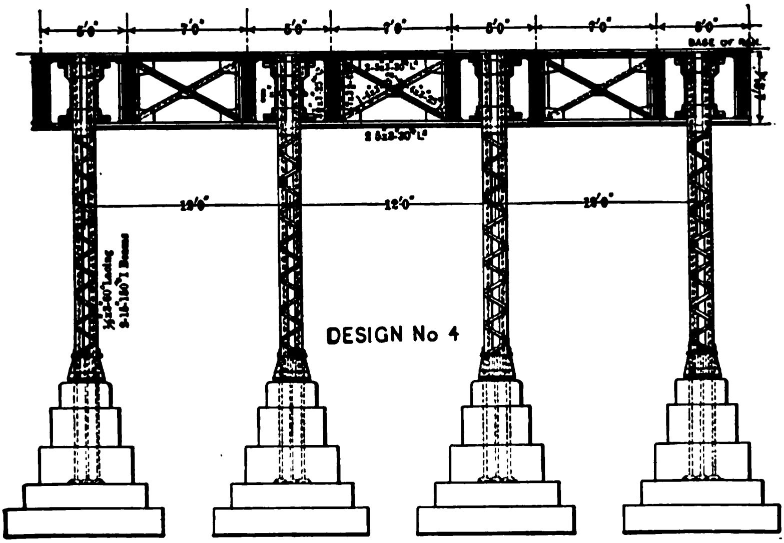


FIG. 15.

Facility of Manufacture and Erection.—In this design all cross-girders and cantilevers must be riveted to the columns in the field, and, owing to the great depth of these girders, this will make this structure difficult to erect. The girders are all heavy and unwieldy, much more so than in the four-column structures. The work in the shops will be easy.

While the structure is, perhaps, apparently a little more economical than Design 1, it has the disadvantages of being unsightly, of lacking rigidity, and of being difficult to erect.

Design 4, Fig. 15.

General Description.—Design 4 differs from Designs 1, 2 and 3 in the fact that no longitudinal sway bracing is used, but each column is made strong enough to take up the longitudinal thrust coming upon it. The spans through the blocks are about 50 ft. long.

This is a four-column, four-track structure, each column being fixed at top and bottom in planes both transverse and parallel to the structure. The columns are anchored to the pedestals by four anchor bolts, instead of the two used in the preceding designs.

Rigidity.—As the longitudinal rigidity is obtained solely through the ability of the columns to resist bending, it is evident that this design will not be as rigid in this direction as Designs 1, 2 and 3. There are no brackets transverse to the structure; hence, it will not be as rigid laterally as Design 1. The stringers are well braced together and to the columns. On curves, transverse sway bracing will be used where permissible, and where it is not the columns will be strengthened so as to take care of the centrifugal load.

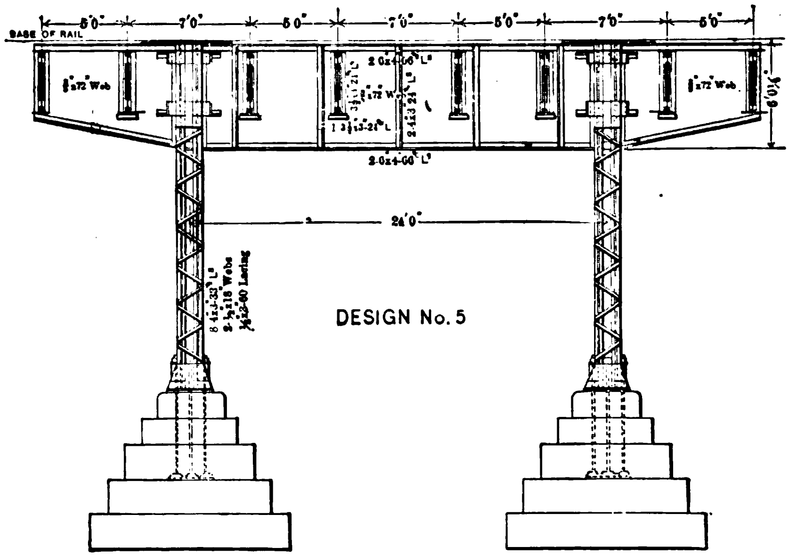


FIG. 16.

Economy.—This is the most expensive design yet considered, the average cost per lineal foot being $66.65 instead of $65.10 for Design 1.

Æsthetics.—Design 4 has nothing to commend it from an æsthetic point of view.

Uniformity of Construction.—Like Designs 1 and 2, this design has the advantage of being adapted to both double and four-track structures.

Facility of Manufacture and Erection.—This design would be easier to erect than Design 3, but not so easy as Design 1. The shopwork would be somewhat difficult.

Design 5, Fig. 16.

General Description.—This is a two-column, four-track structure, and, like Design 4, has no longitudinal sway bracing. The columns are built up of plates and angles, and are designed to carry the longitudinal and transverse thrusts due to braked trains and to wind load. The spans are of the same lengths as in Design 4.

Rigidity.—The remarks made under this head for Design 3 apply to Design 5 as well; but, in addition to the defects of the former, Design 5 lacks the longitudinal sway bracing, and so will not be as rigid as Design 3.

Economy.—Design 5 is the most expensive design on the list, the cost per lineal foot being $67.60.

Æsthetics.—Like Design 4 it has no commendable features in this respect.

Uniformity of Construction.—Like Design 3 this style of structure could only be made to apply to the four-track railway.

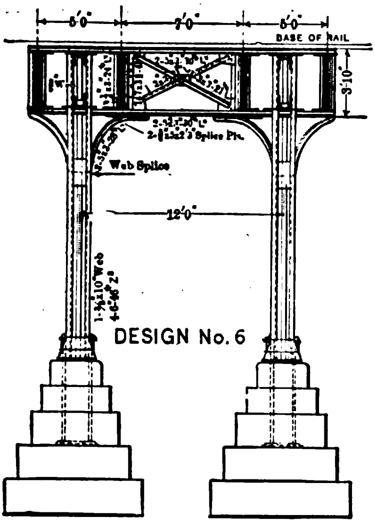


FIG. 17.

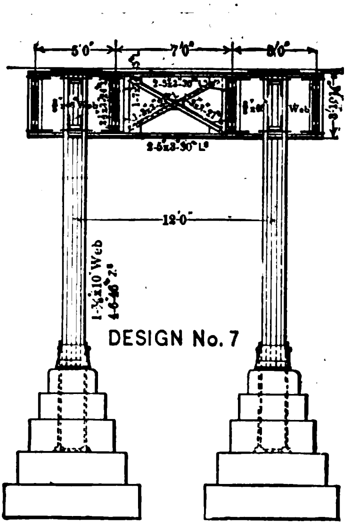


FIG. 18.

Facility of Manufacture and Erection.—The style of columns used would be somewhat difficult to manufacture, and the great amount of field riveting would make the erection expensive.

From the foregoing facts it will be seen that this design has several disadvantages and is also very expensive, although it has some good features.

Design 6, Fig. 17.

General Description.—Design 6 is similar to Design 1, but is a double-track structure. The remarks under Design 1 in relation to rigidity, æsthetics, and facility of manufacture and erection apply to this case also.

Economy.—The cost per lineal foot is $32.65.

Uniformity of Construction.—By using this design for double-track structure and Design 1 for the four-track structure, the design will be the same for columns, stringers, bracing towers, expansion ends, etc., throughout the whole line. If at any time it be considered necessary to convert the double-track structure into a four-track structure, it can be done by simply adding a column at each side of the double-track structure, and putting in the additional stringers, cross-girders, and sway bracing.

Design 7, Fig. 18.

Design 7 bears the same relation to Design 2 that Design 6 bears to Design 1. The cost per lineal foot will be $32.65.

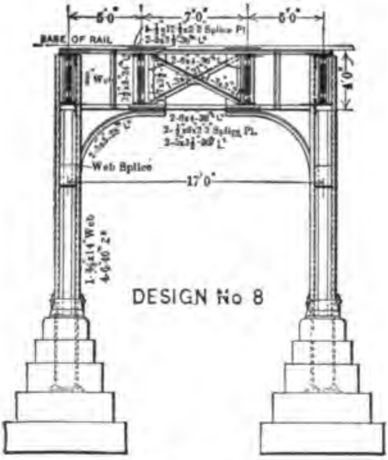


FIG. 19.

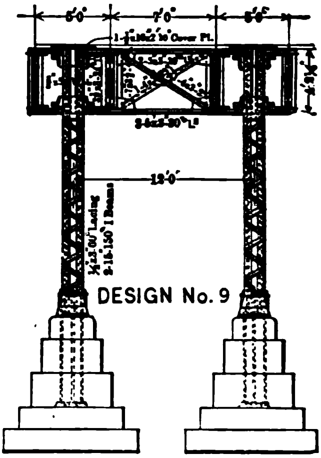


FIG. 20.

Design 8, Fig. 19.

General Description.—In this design, which is for double track, the columns are made of four **Z**-bars, as in Designs 1, 2, 3 and 6, but instead of the columns being directly beneath the center of the tracks, they are placed beneath the outer stringers, thus making the spacing 17ft. centers, transverse to the structure.

Strength.—The end webs in the cross girders extend through the columns, forming the webs of the latter at the top, and pass down far enough to form good brackets, thus making the column, end of cross girder, and brackets all in one piece, which is riveted up solidly in the shop. This makes a very strong connection.

Longitudinal bracing towers are used as in Designs 1, 2, 3, 6 and 7.

Rigidity.—This design is thoroughly braced in all directions, and will be very rigid; but as the columns are attached to the outer stringers, and as the inner stringers are supported by the cross-girders, it is probable that there will be some unequal deflection in the stringers; otherwise this design will be as rigid as Design 6.

Economy.—This is the cheapest design on the list for a double-track structure, the average cost per lineal foot being $32.30, while Designs 6 and 7 each cost $32.65. This shows a saving of 35 cents per lineal foot, or $1,850 (nearly) per mile of double track.

Æsthetics.—The cross-section of this design is probably the most æsthetic of any of the designs, and the side elevation at street crossings can be improved by putting in longitudinal brackets beneath the outer stringers.

Uniformity of Construction.—This design necessitates considerable change in the style of construction from that used in the four-track structure, and it would be difficult ever to convert the double-track structure into a four-track structure in case it should be considered advisable to do so at some future time.

Facility of Manufacture and Erection.—The style of columns and cross-girders used dispenses with nearly all of the field riveting, and will make this a very easy structure to erect. In the shop the work will also be very easy. The lateral system on curves and the stringer bracing used throughout the structure will be easier to connect to the columns and stringers in this design than in any of the other double-track structures now under consideration.

With the exception of the lack of uniformity in construction this design probably offers more advantages than any other for the double track structure.

Design 9, Fig. 20.

Design 9 is a double-track structure similar in construction to Design 4, and the remarks made under the latter in relation to strength, rigidity, economy, æsthetics, uniformity of construction, and facility of manufacture and erection apply to this case also. The cost per lineal foot is $33.31.

Design 10, Fig. 21.

Design 10 is different from any of the designs yet considered, for in all these the columns are carried up to the tops of the cross-girders, while in this the column is carried up only to the plane of the bottom of the stringers, the top of the column being flared out wide enough to receive the two track stringers, which are spaced 5 ft. centers. No longitudinal bracing is used, hence each column is figured to take up in bending its share of the longitudinal thrust.

The columns are made of two **I**-beams, well laced from the bottom up to the point where the flaring begins, and from this point to the top a large plate is riveted on each of the transverse faces of the column. This design is somewhat similar to the one used on the Metropolitan Elevated Railway of Chicago.

Strength.—Design 10 has been made amply strong in all of its parts.

Rigidity.—As the columns are placed directly beneath the center line of the tracks as in Designs 1, 2, 4, 6, 7 and 9, there will be but little vibration or deflection so far as the vertical loads are concerned, but as the columns are not carried up to the tops of the stringers and cross-girders, it is impracticable to make the structure rigid against the longitudinal thrust due to braked trains. Longitudinal brackets have been used to fix the upper ends of the columns; but as each of these brackets has to take hold at the center of a small **I**-beam 5 ft. long, it is evident that the only rigidity that can be procured in this way is dependent upon the efficiency of this **I**-beam to resist bending, and a very small deflection in the **I**-beam will permit of considerable deflection in the column. With this bracket and connection, it is not legitimate to call the column fixed at the top. The stringers are well braced together, and the structure would be very rigid laterally, both on tangents and on curves.

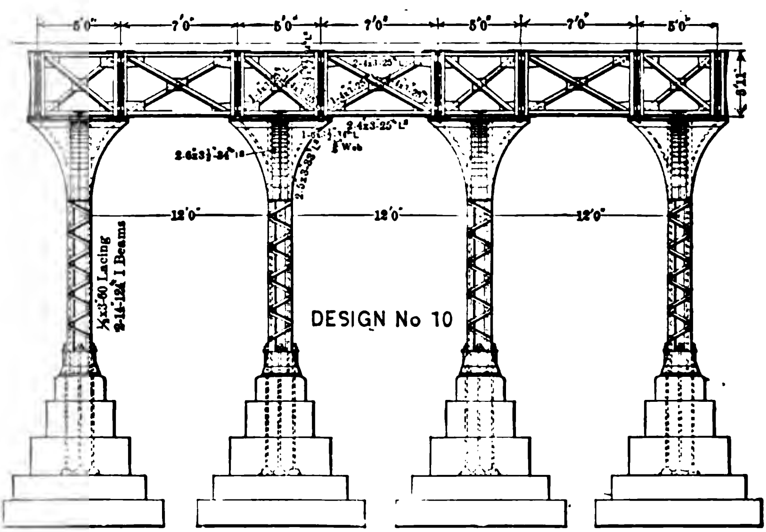


FIG. 21.

Economy.—This design will cost $67.22 per lineal foot, while Design 1 costs but $65.10; hence, Design 1 costs $2.12 less per lineal foot or about $11,200 less per mile than Design 10. The pedestals are more economical in Design 10 than in Design 1, owing to the greater span length used in the former. The additional cost is due to the great amount of metal required to provide for the longitudinal thrust.

Æsthetics.—Design 10 has probably as much to commend it from an æsthetic point of view as any of the designs under consideration.

Uniformity of Construction.—This design, like Designs 1, 2 and 4, can also be used on the double-track structure without any changes in the columns or cross girders.

Facility of Manufacture and Erection.—This design is very easy to erect, as there is very little riveting to be done in the field. The stringers rest upon the flaring tops of the columns and require only a few rivets to hold them in place. There would be about the same amount of field riveting to be done in this design as in Design 1. There is considerable curved work in both plates and angles in the details at tops of columns, which details are rather complicated; hence the shopwork will be expensive and unsatisfactory.

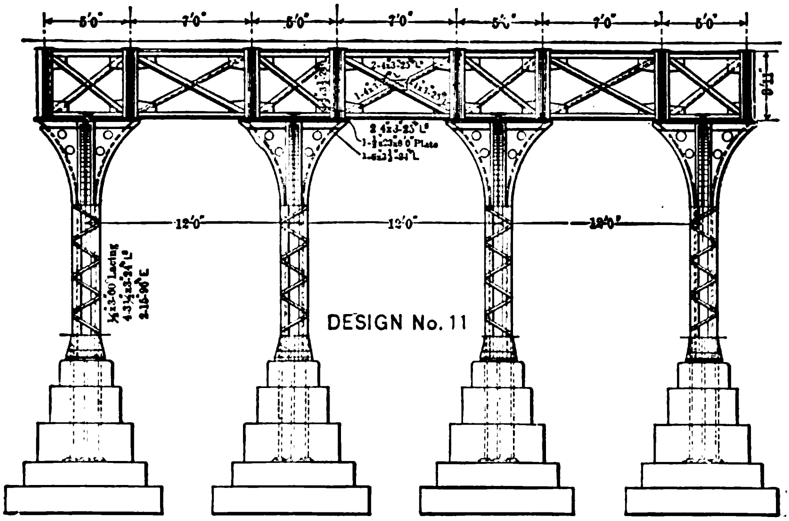


FIG. 22.

From the foregoing facts it is evident that Design 10 offers but few advantages and is also an uneconomical structure.

Design 11, Fig. 22.

Nearly all that has been said in regard to Design 10 applies also to Design 11, the principal difference in the two designs being in the sections used for the columns. In Design 11 there are two 15-in. channels strengthened by 3½ x 3-in 23-lb. angles, and near the top the channels are curved outward, so as to provide bearing for the stringers or longitudinal girders. Experience shows that these curved channels are liable to crack.

The cost of Design 11 is exactly the same as that of Design 10. The same provisions are made for longitudinal thrust, but Design 10 would be easier to manufacture, and would be preferable to Design 11.

Design 12, Fig. 23.

Design 12 is for the alternative route, and is therefore to be placed in the street. Instead of having the columns located in the roadway, as in the Wabash Avenue Extension of the Lake Street Elevated, they will be placed back of the curb lines on the sidewalks, and a heavy cross girder will span the roadway and support the longitudinal girders, which will be spaced, as in all the other designs, 5 ft. centers, with the two tracks 12 ft. centers. No longitudinal sway bracing can be used, therefore the columns are figured to take up the thrust by bending. The column section will consist of one 15-in. I-beam riveted between two 15-in. channels turned face to face.

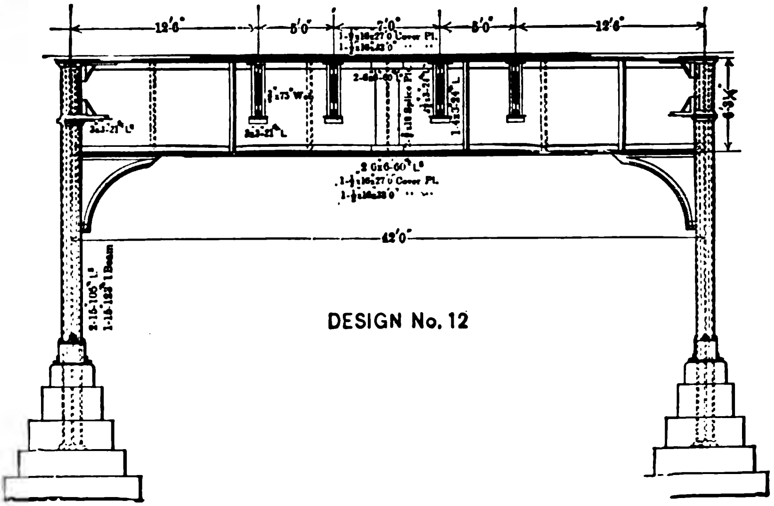


FIG. 23.

Strength.—This design is made very strong, and is thoroughly braced laterally. The columns are each anchored to the pedestals by four anchor bolts which fix their feet, while the tops are fixed by heavy struts extending from the columns to the stringers.

Rigidity.—Owing to the great distance between the columns, transverse to the structure, this design will not be as rigid as Designs 6 and 7, but every precaution has been taken to avoid vibration and deflection. An efficient lateral system has been provided throughout, on tangents as well as on curves, and it will be as rigid a structure as could be expected on this plan.

Economy.—This cannot be called an economical design when compared with the preceding designs for double track structures, as the total cost per lineal foot amounts to $42, while that for Design 8 is but $32.30. This excessive cost is due to the spacing of the columns and the extra weight of cross girders this involves.

Facility of Manufacture and Erection.—This will be a very easy design to manufacture, as it is all straight work; the erection, however, will be much more difficult than that of any of the other double-track structures under consideration, owing to the large number of field rivets to be driven and the great weight of the cross-girders.

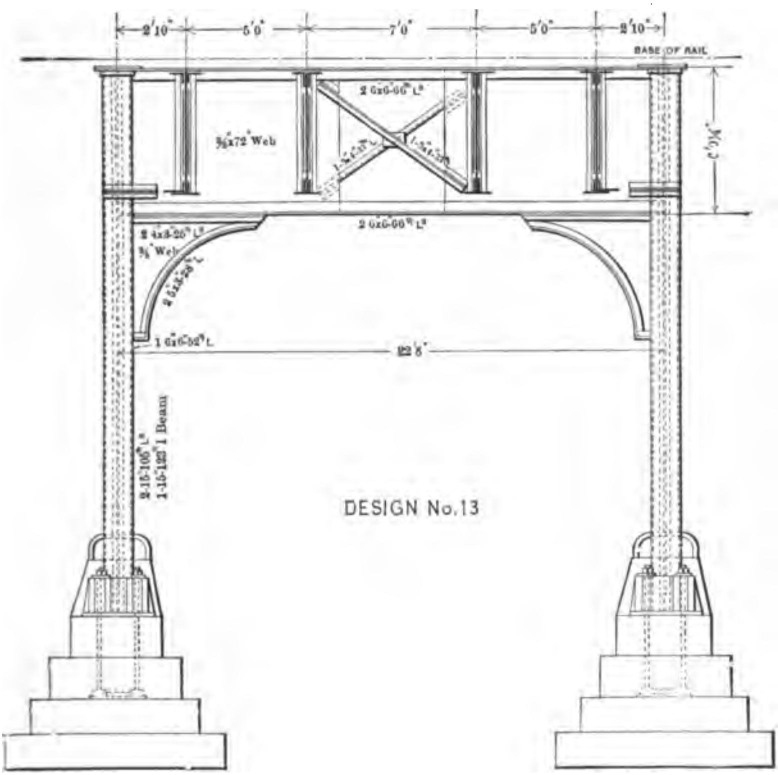


FIG. 24.

Design 13, Fig. 24.

Design 13 is also for the alternative route in case a franchise can be secured permitting the columns to be placed in the roadway. This design is similar to the Wabash Avenue Extension of the Lake Street Elevated, but plate girders will be used throughout for the stringers. The estimate for Design 13 is based upon the assumption that the columns can be spaced 17 ft. centers on Franklin Street and 22 ft. 8 in. centers on the remainder of the line.

The average cost of Design 13 would be $36.81 per lineal foot, involving a saving of $5.19 per lineal foot over Design 12, or about $27,400 per mile.

SUMMARY OF COST.

Design.	Weight per lineal foot on tangent.	Weight per lineal foot on curves.	Cost of line per lineal foot.	Cost of line and stations per mile.
1.........	1 565	1 765	$65 10	$383 728
2.........	1 565	1 765	65 10	383 728
3.........	1 590	1 790	64 60	381 088
4.........	1 700	1 920	66 65	391 912
5.........	1 750	1 950	67 60	396 928
6.........	775	875	32 65	210 000
7.........	775	875	32 65	210 000
8.........	770	830	32 30	208 544
9.........	850	960	33 31	213 876
10.........	1 725	1 950	67 22	394 921
11.........	1 725	1 950	67 22	394 921
12.........	1 142	1 182	42 00	267 760
13.........	916	966	36 81	240 357

In the preceding table there have been assumed four stations to the mile. In the four-track structure one of these is an interior station and the other three are exterior stations, while in the double-track structure all are, of course, exterior stations.

It is in order now to discuss faulty details in existing elevated railroads. This will be done without reference to any road or roads in particular, as the sole object of this discussion is to call attention to important defects in order that they may be avoided in future work.

1.—INSUFFICIENCY OF RIVETS FOR CONNECTING DIAGONALS TO CHORDS OF OPEN-WEBBED, RIVETED GIRDERS.

This defect is more noticeable in old structures than in later ones, especially as the tendency nowadays is very properly to substitute plate-girder for open-webbed construction. In many of the older elevated roads there is no connecting plate between the diagonal and the chord, but one flange of each of the angles in the diagonal is riveted directly to the vertical legs of the chord angles. This detail involves the use of either two or four rivets to the connection, which is evidently very bad designing, as there should be more rivets used, even if the diagonal stresses do not call for more on purely theoretical considerations. Where the theoretical number of rivets is very small, additional rivets should be used for two reasons, viz.: first, one or more of the rivets may be loose, and, second, there is nearly always a torsional moment on each group of rivets owing to eccentric connection.

2.—FAILURE TO INTERSECT DIAGONALS AND CHORDS OF OPEN-WEBBED GIRDERS ON GRAVITY LINES.

It is very seldom indeed that the designer even attempts to intersect at a single point all of the gravity lines of members assembling at an apex. The failure to do so involves large secondary stresses, especially in the lighter members. By using connecting plates, it is always practicable to obtain a proper intersection; and it is always better to do this than to try to compensate for the eccentricity by the use of extra metal for the main members.

3.—FAILURE TO CONNECT WEB ANGLES TO CHORDS BY BOTH LEGS.

Some standard bridge specifications stipulate that in case only one leg of an angle be connected, that leg only shall be counted as acting, although this stipulation is generally ignored by the designer working under such specifications. It is seldom, indeed, that both legs are connected. In order to settle the question of the necessity for this requirement, the author has had made, in connection with his Northwestern Elevated work, a series of tests to destruction of full-size members of open-webbed girders, attached in the testing machine as nearly as practicable in the same way as they would be attached in the structure. It was intended to settle by these tests the following points: first, effect of connecting by one leg only; second, effect of eccentric connection; and, third, the ultimate strength of star struts with fixed ends, each of these struts being formed of two angles. As these tests are not yet finished, their results cannot be given here. The principal deduction to be made from the tests thus far completed is that an equal-legged angle riveted by one leg only will develop about 75 per cent. of the strength of the entire net section, while a 6 x 3½-in. angle riveted through the longer leg will develop about 90 per cent. It is therefore more economical for short diagonals to use unequal-legged angles connected by the longer leg than to employ supplementary angles to try to develop the full strength of the piece. In fact, the experiments made up to date indicate that these supplementary angles will not strengthen the diagonal essentially. However, further experiments may show the contrary.

4.—FAILURE TO PROPORTION TOP CHORDS OF OPEN-WEBBED LONGITUDINAL GIRDERS TO RESIST BENDING FROM WHEEL LOADS IN ADDITION TO THEIR DIRECT COMPRESSIVE STRESSES.

This neglect is common enough in the older structures, and the fault is a serious one, although the stiffness of the track rails and that of the ties tend to distribute the load and thus reduce the bending.

5.—INSUFFICIENT BRACING ON CURVES.

Too often in the older structures the curved portions of the line are no better braced than are the straight portions. A substantial system of lateral bracing on curves extending over the entire width of the structure and carried well into the tops of the columns adds greatly to the rigidity of the structure, and, consequently, to the life of the metal-work.

6.—INSUFFICIENT BRACING BETWEEN ADJACENT LONGITUDINAL GIRDERS.

The function of the bracing between longitudinal girders is an important one, for it is the first part of the metalwork to resist the sway of trains. Not only should the top flanges of adjacent girders be connected by rigid lateral bracing, but the bottom flanges should be stayed by occasional cross-bracing frames, one of the latter being invariably used at each expansion end of each track.

7.—PIN-CONNECTED PONY TRUSS SPANS AND PLATE GIRDERS WITH UNSTIFFENED TOP FLANGES.

These defective constructions are noticeable in some of the older lines, but fortunately, not often in the newer.

What the ultimate resistance of the pony-truss structure is no man can tell without testing it to destruction; but in the opinion of most engineers it is much less than it is assumed to be by those designing pony-truss bridges.

8.—EXCESS OF EXPANSION JOINTS.

Too many expansion joints in an elevated railroad are nearly as bad as too few. In the former case the metal is overstrained by the vibration induced by the lack of rigidity, while in the latter case it is overstrained by extreme variations of temperature. There are elevated roads in existence with expansion joints at every other bent, and there is one with them at every bent. For long spans there should be expansion provided at every third bent, and for short spans at every fourth bent.

9.—Resting Longitudinal Girders on Top of Cross Girders Without Riveting Them Effectively Thereto.

This is by no means an uncommon detail, especially in the older structures. It is conducive to vibration, and its only advantages are ease of erection and a cheapening of the work by avoiding field riveting.

10.—Cross Girders Subjected to Horizontal Bending by Thrust of Trains.

The resistance that can be offered by a cross girder to horizontal bending is very small; nevertheless, cross girders are rarely protected from the bending effects of thrusts of trains. What saves the cross girders from failure is the fact that the continuity of the track tends to distribute the thrust over a number of bents. Nevertheless, it is not legitimate to depend on this fact; for, especially on sharp curves, the tendency is to carry the thrust into the ground as directly as possible. In the author's opinion the only proper way to provide for this thrust is to assume that 20 per cent. of the greatest live load between two adjacent expansion points will act as a horizontal thrust upon the columns between these two expansion points; and all parts of the metal-work should be proportioned to resist this thrust properly.

By running a strut from the top of each post diagonally to the longitudinal girder at a panel point of its sway bracing, the horizontal thrust is carried directly to the post, and a horizontal bending moment on the cross girder is thus prevented. Such construction should invariably be used where the conditions require it.

11.—Cutting Off Columns Below the Bottom of Cross Girders and Resting the Latter Thereon.

This style of construction, which until lately was almost universal, is extremely faulty in that there is no rigidity in the connection, and that the column is thus made more or less free-ended at the top.

It has been said that no harm is done to the column by making it free-ended, as it can then spring better when the thrust is applied. Unfortunately, this reasoning is fallacious, because the few unlucky rivets which connect the bottom of the cross girder to the top of the column tend to produce a fixed end, and are, in consequence, racked excessively by the thrust of the train. In all cases the column should extend to the top of the cross girder and should be riveted to it in the most effective manner practicable.

12.—PALTRY BRACKETS CONNECTING CROSS GIRDERS TO COLUMNS.

Brackets are often seen composed of a pair of little angles attached at their ends by two or three rivets. Such brackets are merely an aggravation, and are sure to work loose sooner or later. It is impracticable to compute the stresses in this detail; nevertheless, good judgment will dictate the use of solid webbed brackets riveted rigidly to both cross girder and column so as to stiffen the latter and check the transverse vibration from passing trains.

13.—PROPORTIONING COLUMNS FOR DIRECT LIVE AND DEAD LOADS AND IGNORING THE EFFECTS OF BENDING CAUSED BY THRUST OF TRAINS AND LATERAL VIBRATION.

The practical effects of this fault can be seen to best advantage by standing on one of the high platforms of one of the elevated railroads in New York City. The vibration, by no means small, from an approaching train can be felt when it is yet at a great distance. Some may claim that this vibration is not injurious; but they are certainly wrong, for what does it matter so far as the stress in the column is concerned whether the deflection be caused by vibration or by a statically applied transverse load, so long as the amount of the deflection is the same in both cases? It takes metal, and considerable of it, to make columns strong enough to resist bending properly, and a sufficient amount should invariably be used to attain this end.

14.—OMISSIONS OF DIAPHRAGM WEBS IN COLUMNS SUBJECTED TO BENDING.

If the diaphragm web be omitted in such a column, reliance must be placed on the lacing to carry the horizontal thrust from top to bottom. But even if the lacing figure strong enough to carry it, which is unusual, it is wrong to assume it so, for the reason that one loose rivet connecting the lacing bars will prevent the whole system from acting, as will also a lacing bar that is bent out of line. Decidedly, every column that acts as a beam also should have solid webs at right angles to each other.

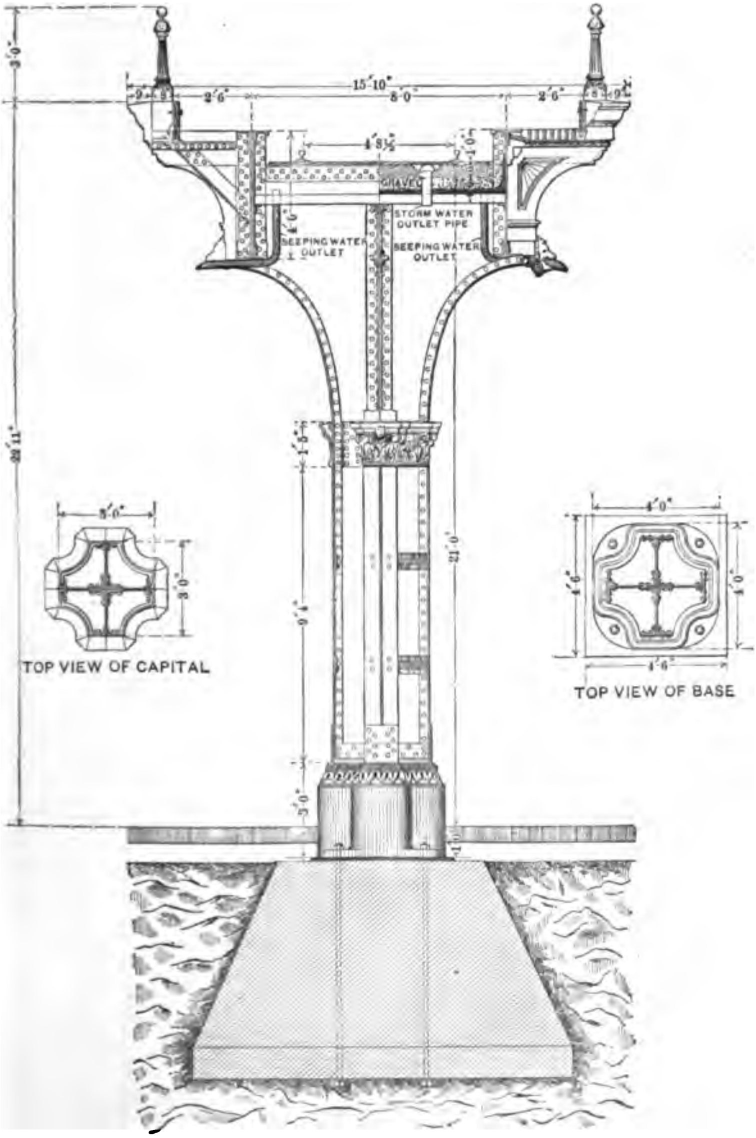

3'0"
15'10"
9"
9"
2'6"
8'0"
2'6"
9"
9"
4'8½"
1'0"
GRAVEL
4'0"
SEEPING WATER OUTLET
STORM WATER OUTLET PIPE
SEEPING WATER OUTLET
22'11"
1'5"
9'4"
21'0"
3"
3'0"
1'0"
3'0"
3'0"
TOP VIEW OF CAPITAL
4'0"
4'6"
4'0"
4'6"
TOP VIEW OF BASE

FIG. 25.

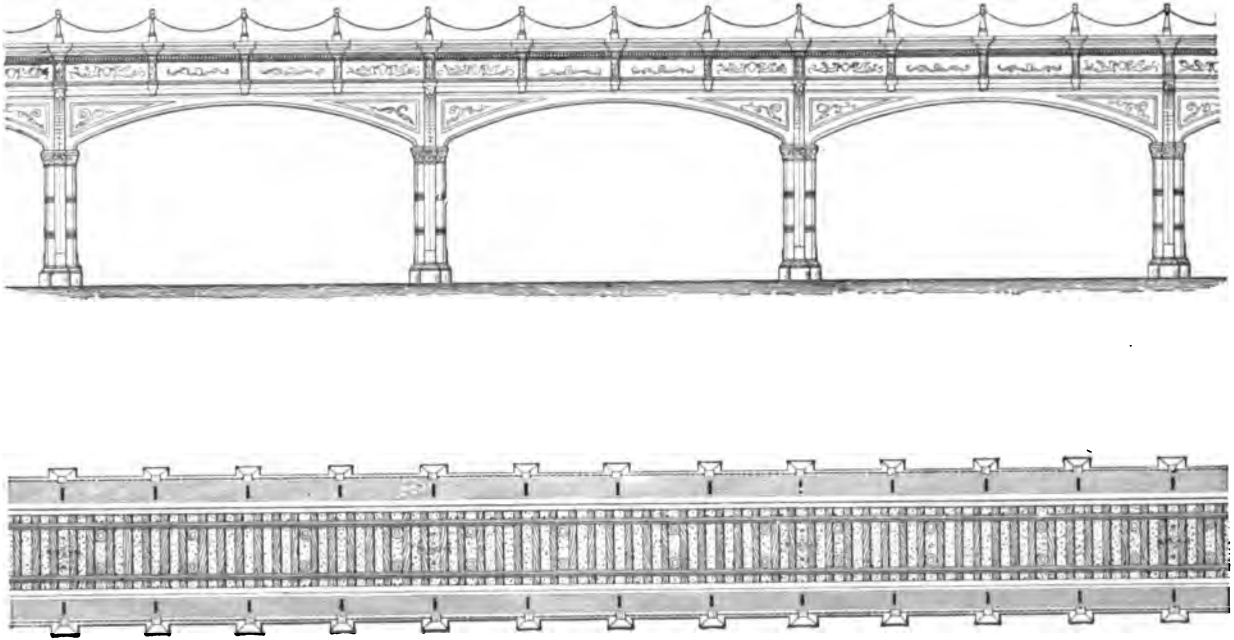


FIG. 26.

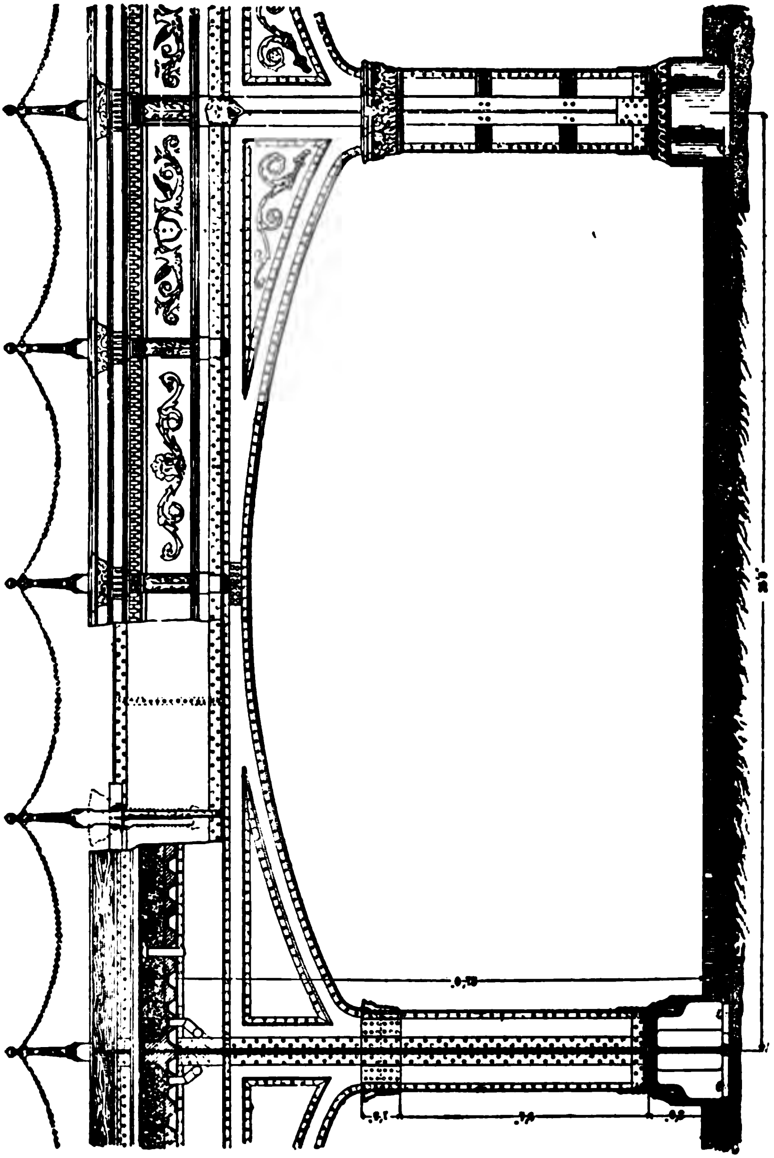


FIG. 27.

15.—INEFFECTIVE ANCHORAGES.

On account of both rigidity and strength every column ought to be anchored so firmly to the pedestal that failure by overturning or rupture would not occur in the neighborhood of the foot, if the bent were tested to destruction. The flimsiness of the ordinary column-foot connection is beyond description.

16.—COLUMN FEET SURROUNDED BY AND FILLED WITH DIRT AND MOISTURE.

The condition of the average column foot is simply deplorable. This is caused by failing to raise it so high above the street as to prevent dirt from piling around it, and by omitting to fill its boxed spaces with concrete. When rusting at a column foot is once well started, it is almost impossible to stop it from eating out the metal rapidly.

17.—INSUFFICIENT BASES FOR PEDESTALS.

False ideas of economy on the part of projectors and indifference on the part of some unscrupulous contractors occasionally cause the use of pedestal bases altogether too small for the loads that come upon them, especially where the bearing capacity of the soil is low. The result is sunken pedestals and cracked metalwork. In figuring the pressure on the base of the pedestals it is not sufficient to recognize only the direct live and dead loads, but it is necessary also to compute the additional unequal intensities of loading caused by both longitudinal and transverse thrusts.

ÆSTHETICS.

In relation to æsthetics in the designing and construction of elevated railroads something may be said, although but little has been done. The extra cost of decorating an elevated structure is certainly considerable, and on this account projectors are chary of attempting to do more than make the work strong and durable, preferring to let the appearance take care of itself. Notwithstanding this, the careful designer can generally manage to make his construction more or less sightly without adding materially to the expense. This the author attempted to do in both the Northwestern and the Loop. It is for others to say whether he has succeeded or not. At the Diversey Street and Sheridan Road crossings of the Northwestern Elevated some extra ornamentation was compulsory, and it was put in at increased expense; but elsewhere no extra money was expended on appearance.

Some time before the Northwestern Elevated was contemplated, and while several parties were trying to obtain concessions for a down-town loop, the author made a special study of an æsthetic type of structure for this locality, in which the consideration of expense cut no figure.

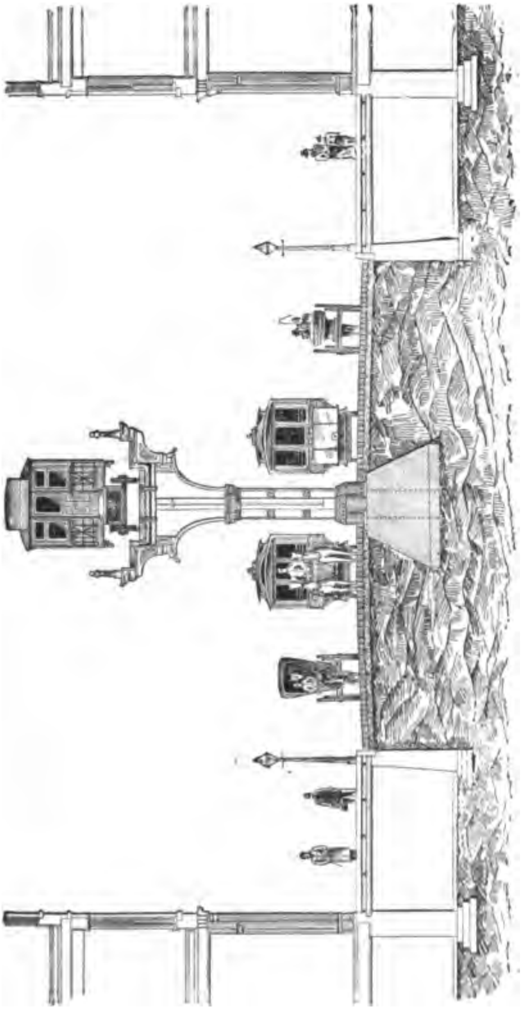


FIG. 28.

The result of his studies is shown in Figs. 25 to 29, inclusive, Fig. 25 being a cross-section of such a structure, Fig. 26 a plan and elevation of a single-track railroad, Fig. 27 a side elevation showing some of the details of construction, Fig. 28 a cross-section of a street with a road of this type, and Fig. 29 a cross-section of the same street with a double-track elevated railroad. These designs involved not only appearance, but also comparatively noiseless operation and freedom from dripping of water on the people beneath the structure. Although no line was built according to these drawings, they have, notwithstanding, proved of practical utility in several ways; and the author now offers them to the engineering profession as his idea of what an elevated railroad for a large city should be where expense is no object and where appearance is the great desideratum.

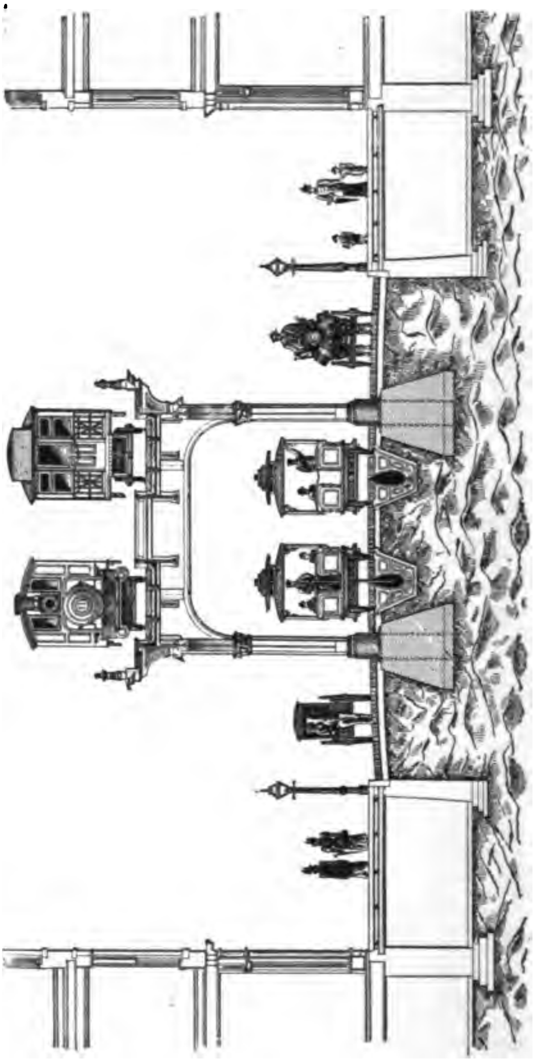


FIG. 29.

DISCUSSION.

By O. F. Nichols, M. Am. Soc. C. E.

Elevated railways are continuous bridges on which the loads are lighter but more frequently applied than on ordinary bridges. No special inspiration is required for their design. If they are built strong enough; if, since they cannot be made beautiful, it is possible to avoid making them ugly; if they are built to suit public convenience and at relatively low cost—then about all has been accomplished that lies in the mind of man to do for the ordinary elevated railways.

It seems that much of the structure treated of in the paper is for four-track service and some of it on private property. The four-track system, like the loop system, is theoretically perfect, and yet seldom used in practice. New York City is probably the only place in which a four-track elevated railway would be bound to be successful, and where four columns under four tracks would be necessary. Designs 3, 6, 7, 8, 9 and 13 are all quite familiar as having been considered, in their essential features, in the studies made for the Suburban Rapid Transit Company of New York City in 1886-87.

For a railway on private property and where the space under the rails cannot be utilized for business purposes, as in cities like Chicago and New York, it seems the better way to build a viaduct; to surround the plot with a retaining wall of concrete and fill in with dirt; then place girders over the cross streets and lay the rails. An estimate made in 1888 showed that such a railway could be built cheaper than the structures considered in the paper.

There have been a number of types of foundation for elevated railways. In no place has the peculiar aversion to concrete been more notable, and in few instances has its use been more satisfactory. The several types of foundation used on the Brooklyn Elevated Railroad are shown in Fig. 30. The reduction in cost, corresponding with the changes in form and material, has been notable, passing from $190 each in 1885 to less than $90 in 1893. It will be seen that the type D, adopted early in 1892, is the one copied in the studies now under discussion. The author has, however, missed the true spirit of the design, and, misled by his column theory, has misused this really serviceable and economical foundation.

In securing the column to the foundation the author repeats, he says, the fastening he used in Sioux City in 1891; he certainly duplicates the fastening designed for the Union Depot shed in St. Louis.

If one were anchoring to solid rock or to massive foundations and resisting much greater stresses, these lugs might be necessary, but when, as in the sketches, 40,000 pounds of tensile strength in anchor bolts is opposed to 13,000 pounds of concrete, and the bolts are doubled for assumed extra stress, while the concrete mass remains the same, the lugs have a questionable value. This fastening keeps the bolts too near the center of the foundation, makes the resistance to rocking depend too much on the stress in the bolts, and is needlessly awkward and expensive.

A striking feature of the designs in the paper is the distribution of material in the columns themselves, in their connections and in the lateral bracing, and in the complex machinations necessary to endeavor to utilize this material. Indeed a series of troubles arises from the opinion that "20 per cent. of the greatest live load between two expansion points will act as a horizontal thrust upon the columns between these expansion points." This is pure fiction; it is not even empirical. There is nothing to justify it. Even the emergency stops in the airbrake tests do not give much more than 10 per cent. of retardation, measured at the rails. If the trains were skidded without wheels, the retardation would hardly reach the figure named. The dynamometer rarely shows more than 4,000 pounds as the pull necessary to start an elevated train, and little, if any more, is needed to stop it. Then this thrust is not concentrated or limited in its action to a few feet of structure; it is spread through the rails and track system and structure generally to the next curve. The actions of the several trains counteract each other to a certain extent, and the net effect may possibly correspond to a pull or thrust at the rails equal to 3 per cent. of the total moving load on a half mile of structure, and would be distributed over about a hundred columns.

There is a phenomenal continuity in these structures. It is impossible to close up an expansion joint except by expansion, which never amounts to as much as the ordinary theoretical requirements, because provision is made for excessive ranges of temperature. Owing to the continuity of the structure there is, in practice, very little lateral stress on the cross girders, even in extreme cases and on curves. The older builders fixed the base of the column, and left the top free to vibrate; the more recent structures have the base of the column held and the top firmly fixed to the transverse girder; as a consequence, the stiffness of the column is brought fully into action and is then generally sufficient to resist the slight tendency to vibration. The recent structures do not vibrate, and have been likened to a common table, in which the legs are securely fastened to the top.

The entire effect of the extension of the lateral system beyond the longitudinal girders is to fix the columns partially at the top. Unfortunately the sketches do not give a clear idea of the details of construction; it would seem, however, as if none of the connections of the columns to the girders are either very simple or thoroughly effective.

No one has ever made a very satisfactory column from I-beams. The Z-bar is somewhat better for column construction, but both sections are unsatisfactory when it comes to connections with girders or with column feet. The author's condemnation of the straight brace and his unqualified approval of the curved bracket are somewhat irrational and will not be generally approved. The curved bracket is unsatisfactory, because it professes so much and accomplishes so little; it is ugly, and, unless very heavy, it is ineffective.

Far too much stress is laid on the necessity for a web plate in a column, especially in a direction transverse to the axis of the structure. It is unnecessary to consider wind pressure, as such, in connection with an elevated railway of the ordinary height. There are, of course, lateral stresses to meet. They are, however, generally quite indeterminate, and may be fully provided for by simply fixing the column to the cross girder at the

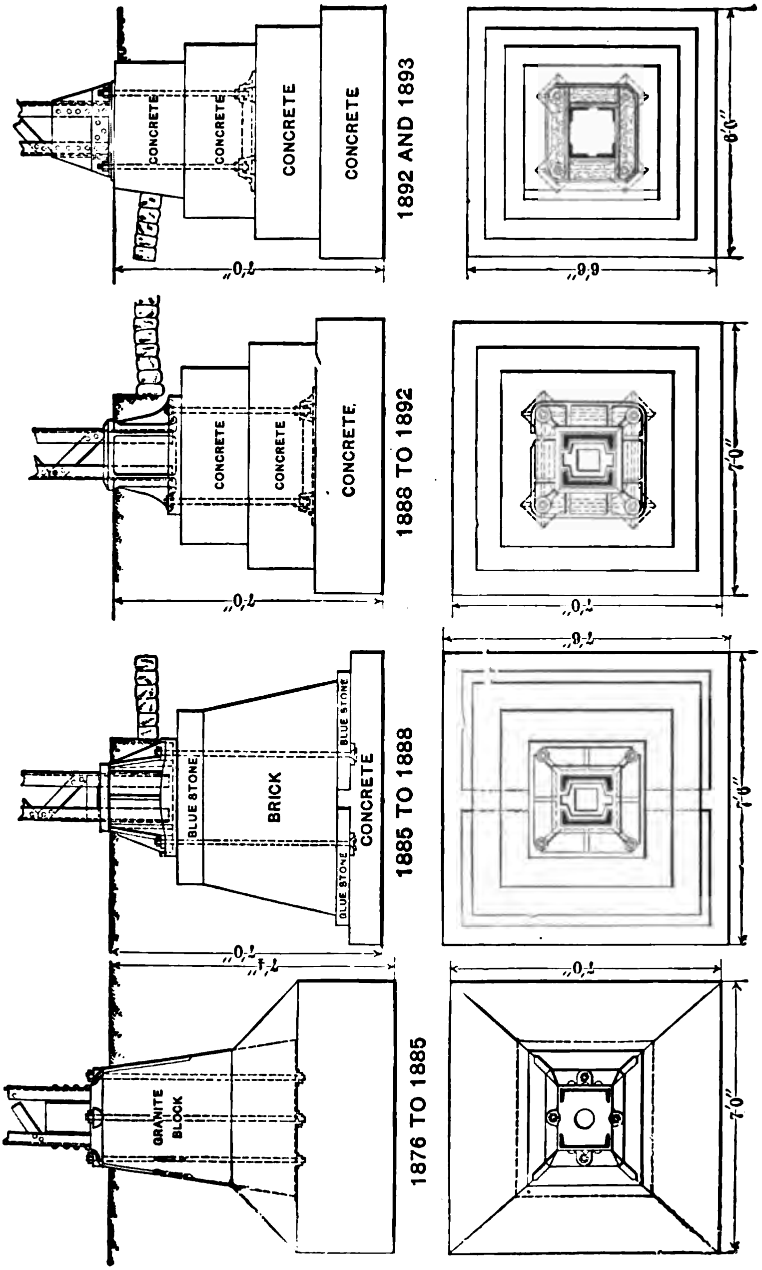

CONCRETE
CONCRETE
CONCRETE
CONCRETE
1892 AND 1893
7'0"
6'6"
6'0"
CONCRETE
CONCRETE
CONCRETE.
1888 TO 1892
7'0"
7'0"
7'0"
BLUE STONE
BRICK
BLUE STONE
BLUE STONE
CONCRETE
1885 TO 1888
7'6"
7'0"
7'6"
7'1"
GRANITE BLOCK
1876 TO 1885
7'0"
7'0"

FIG. 30.

top, and providing a double-riveted lacing of the column in this, lateral direction.

It certainly seems strange that Designs 12 and 13 should have much larger column sections than Design 3, which may easily have twice as great a load. This all follows quite logically, however, from the use of the column theory prescribed in the paper. It would be interesting to see, and weigh, the lateral brace for Design 3, when properly made to satisfy this column theory.

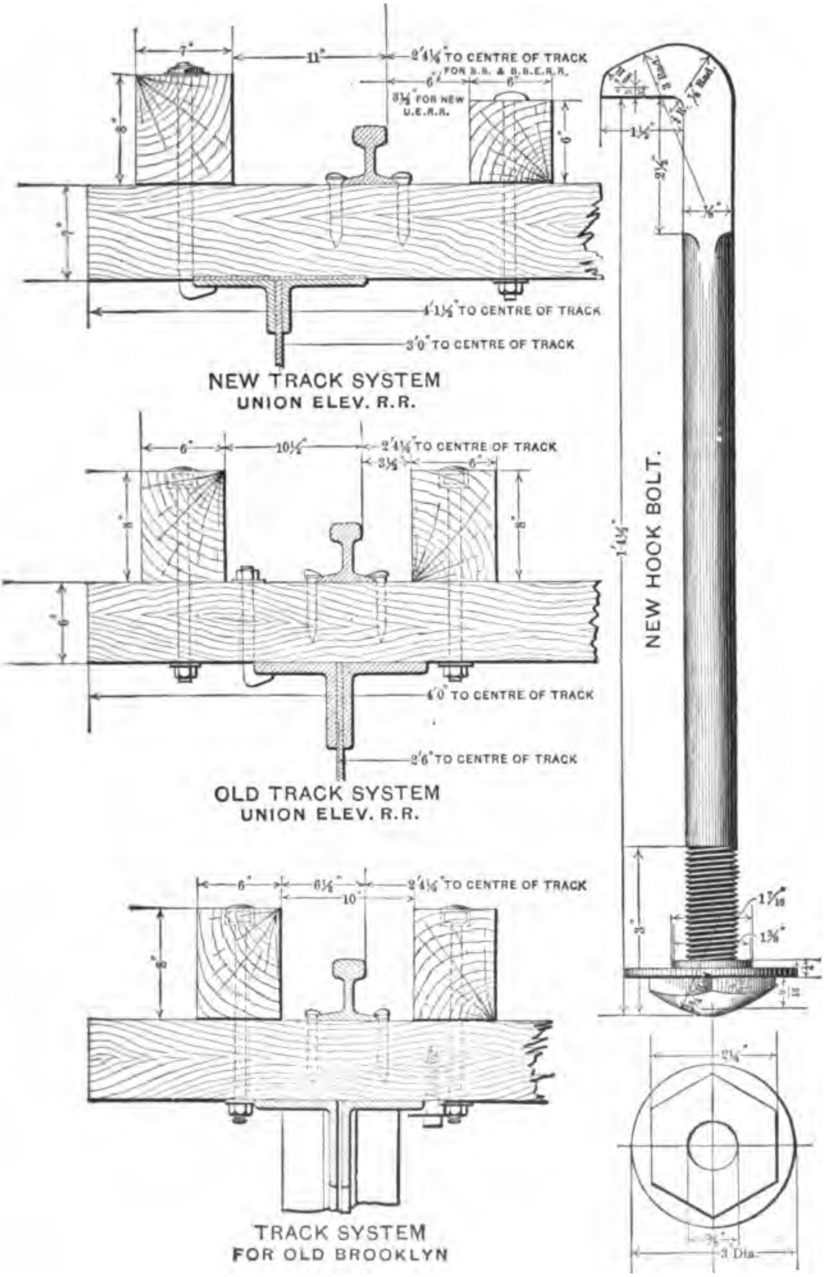
The expansion pocket (Figs. 8 and 9) has nearly all the defects of the old strap pocket of a generation ago, and is, constructively, a corruption of a pocket designed by Theodore Cooper, M. Am. Soc. C. E., in 1886, for the Suburban Rapid Transit Company, and since used on the Brooklyn road, with a reduction of the length of the lever arm of the load. Expansion joints need not be placed nearer together than 200 to 250 feet; the latter distance was used latterly in Brooklyn, the joints occurring at the middle of every city block. These structures do not reach the high ranges of temperature generally assumed, and rarely expand and contract more than 1-2 inch in 100 feet, and often not so much.

It is important that the cost of elevated structures should be kept down, although there is a possibility of exaggerating the importance of this matter. For the New York City roads, the interest on the present cost of stronger structures would constitute less than 15 per cent. of all annual expenditures. The problem is to get the best effect for the least money, i. e., for the least weight of structure. It has been well said that existing elevated structures have plenty of material in them, but not rightly distributed. In this respect, the studies of the paper mark but slight advance over previous practice.

One of the most economical structures ever built was the stem line of the Suburban Rapid Transit Company. It was located on private property except at street crossings, and had but two tracks, although these were located with reference to the possible addition of two more. Masonry piers were used on the private property, instead of columns. Continuity of structures was not necessary or desirable; the longitudinal girders rested on iron plates placed on the granite coping of the brick piers. One end of each girder was fixed, the other slotted over ¾ inch bolts set in the coping. There was absolutely no vibration; the bents were substantial, imperishable and economical; the cost of the structure for double track was about $35, and a type was designed estimated to cost $30 per lineal foot. The loading was nearly twice that provided for in the paper under discussion.

The following approximate data for the Brooklyn Elevated Railroad is based on actual construction rather than on studies, and excludes siding. yards, water, coaling and interlocking plant, and all stations, other than noted, and reduces the cost of structure to 3 cents per pound.

	Old Brooklyn Lines.	Later Union Lines.	Sea-Side Lines.	Fulton Avenue Extension.
Average length of spans	44.7 ft.	59.9 ft.	52.5 ft.	
Weight of structure per lineal foot..........	870 lbs.	1 050 lbs.	1 130 lbs.	950 lbs.
Cost of structure per lineal foot, including foundations.	$34 70	$36 50	$37 40	$32 00
Cost per mile, including passenger stations...	. . ..	308 000 00	286 950 00	213 900 00
Percentage of cost of bents to cost of spans..	75%	69%	65%	



NEW TRACK SYSTEM
UNION ELEV. R.R.

OLD TRACK SYSTEM
UNION ELEV. R.R.

TRACK SYSTEM
FOR OLD BROOKLYN

NEW HOOK BOLT.

FIG. 31.

The length of span is about the same as that recommended by the author, but the percentage of cost of bent to cost of span is much less. If the "true theory of economy" is correct, about 30 per cent. should be added to the cost of these Brooklyn bents, and since this must be put into the metal, the foundations being the same, it would add about 12,000 pounds of metal to these bents, which has, heretofore, been considered unnecessary.

The track system of the Manhattan Railway seems to have been accepted without much question. This system illustrates the persistency of minor errors and the ability of individuals to perpetuate their idiosyncrasies. The ties are not thick enough, nor is the outer guard rail wide enough. The inner guard rail is of little use in new structures, other than to space the ties and to give a sort of moral confidence to the timid, and these are its principal uses in the recent Brooklyn lines. If the only objection to projecting nuts was the danger of tripping one up in walking over the track, they would not be so studiously avoided or yield so easily to the cuspidors formed by the Manhattan cups. Fig. 31 illustrates the principal types of track system used on the Brooklyn lines.

The beveled ties provided for in the studies of the paper were first used on the Brooklyn lines in 1889, and had, no doubt, been used before that time, if not on elevated railways. They are theoretically all right, but the trackmen prefer the old wedge block as more convenient to handle and reset. The author apologizes for a compromise between theory and practice in using low elevations of the outer rail on curves, and says, "experience in operation alone will tell whether the decision of the company's engineers in the matter is correct." There need be no uncertainty on this score; these low elevations have been in use on all elevated railways from the beginning. There is no compromise with theory, since the lower elevations correspond with the slower speed absolutely required on sharp curves to avoid unseating the passengers.

It is unfortunate that the details of the longitudinal girders and their connections are not given in the paper, as there are indications that close adherence to the scholastic methods has led to the retention of some of the antique errors of girder construction.

The simpler an elevated railway can be built, the better; the smaller the number of parts and the simpler the shapes of those parts, the more satisfactory will the work be. No attempt at ornamentation should be tolerated, and the illustrations in the paper show this to be true. Ornament, to be good, must be necessary, and must be true. These conditions are not satisfied on elevated railways, except in the most rigorous simplicity of treatment.

The columns, in the aesthetic studies, are very large, and the spans inconveniently short. The arch span has no practical value. It does nothing that could not be better done without it; it is, in consequence, insincere and misleading and cannot be justified. It is intended to hide the girder, which really does the work, and is therefore a deluding member.

The aesthetic structure does not seem to require the heavy holding-down lugs and bolts of Designs 1 to 13; it will, perhaps, hold itself down. Here is, indeed, a structure, Figs. 27 and 29, which does not require holding-down bolts; which could, in fact, be skidded along over thick ice on its feet without falling simply because its legs are stiff enough and are well fastened to its body. In this respect it sustains the recent practice in the East, if it does not fully satisfy the theories of the paper.

By Henry B. Seaman, M. Am. Soc C. E.

In studying the requirements and the necessary expedients of an engineering problem, and in making the usual examination and research for precedent, many features will be found which indicate the influence of extraneous conditions over which the engineer has no control. This may be considered to have been the cause of such details in elevated structures as the use of flat plates for the main compression diagonals of lattice girders, or the construction of cross girders with inclined end posts, and with no other column connection than that afforded by an iron casting; but, though such details may, indeed, teach how not to do it, to say there are no other lessons to be learned from these structures is to forget that when first constructed some twenty years ago, they were unprecedented, and their better and more successful features have become so blended with general practice that even the examining engineer may fail to recognize the very source of his better information. These elevated roads, after twenty years of service, under loads exceeding those for which they were designed, show no indication of such deterioration as would justify the prediction of the author that they will eventually be reconstructed because of their faulty details.

There are several features of these elevated roads which are worthy of consideration by those engaged in the most recent practice, and one of these is the effect of the longitudinal thrust of stopping trains. The use of the co-efficient of 20 per cent. is extreme, even on a purely theoretical basis, as an examination of the tests of efficiency of air brakes will show. These tests, made under exceptionally favorable circumstances, show a resistance of about 15 per cent., and when it is considered that the compact wooden floor system distributes such force indefinitely, it may be doubted if the resulting strains are of any considerable importance. Vibration must occur so long as iron has elasticity, but that such vibrations produce excessive strains, or in any way injure the structure, is not indicated by experience. If the vibrations are unpleasant, the remedy is to build stations and platforms upon separate foundations, with no connection to the main girders.

The speaker had already discussed the use of steel.* Though the exigencies of manufacture have practically eliminated the general use of fibrous wrought iron, it is reassuring to note the gradual progress toward a soft steel on account of its greater uniformity and freedom from hard spots. It seems to be the growing opinion among engineers, that the use of high or medium steel so increases the contingencies of failure, due to hardness, that a decrease of section is not warranted.

The shop coat of paint should, in the speaker's judgment, be one which will not conceal defects of manufacture, and for that reason he advocates the use of pure boiled linseed oil; but for a permanent coat of paint there is probably nothing much better than red lead, unless experience should prove that carbon paints afford better protection against locomotive fumes. Some time ago, while examining a railroad bridge which had oxide of iron paint on compression members, and lead paint on tension members, both applied about four years previously by the same painters, the oxide of iron showed heavy scales and rust, while the lead was still in perfect condition.

In rail sections it would hardly seem necessary to go beyond those recommended by the Committee of this Society, which was composed of mem-

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*Transactions, Vol. xxvi., p. 230.

bers of special experience, and whose report was the result of extended deliberation.

The author's device for securing a truly fixed base of column is a good one, but the cast-iron bases of the New York roads have been entirely efficient, and in these cases the anchor bolts extend nearly to the base of foundations, instead of half way through, as the author shows. The detail of expansion joint is likewise thoroughly scientific, and a similar device has been extensively used in the vicinity of New York with very satisfactory results. The old style of pocket, formed merely of a bent plate, has, at times, proved weak at the bend.

The estimates of cost presented by the author are extremely interesting and valuable, but should not be considered with undue refinement, without the details on which they are based. For instance, Designs 6 and 7 are stated to be alike, except the additional brackets on No. 6, yet the estimate for each is the same; also, Design 8 has cross girder strains and brackets, yet it is said to be less expensive than No. 7. Again, in the comparison of plans, he places the four-column structure on the same basis as that with two columns, though he does not state whether or not he has considered the fact that the four-column structure would receive its maximum column load from each train that passes over it, while the two-column structure would practically never receive such strain.

While his brother engineers may differ from him in a number of details, it is not intended to detract from those main features of the author's paper which are beyond criticism, and for the presentation of which all are indebted. He is likewise to be congratulated upon receiving the endorsement which has enabled him thus to adhere to the most advanced practice.

By T. C. Clarke, Past-President Am. Soc. C. E.

The author gives a list of sixteen "essentials" to good elevated railway construction. Having laid down the law, he went on a tour of observation to see if it had been followed. The results were unsatisfactory. He went believing "that the methods in vogue for constructing elevated railways were radically wrong," and came back having accumulated "a great mass of information showing how not to do it." If he had carefully examined and correctly reported the condition of the Second Avenue structure of the Manhattan Elevated Railway of New York, he must have admitted that it conforms in general design to all of his sixteen "essentials," although in detail there are many differences.

The speaker took direct issue with the author's sweeping statement, and maintained that this structure, although designed twenty years ago, is not radically wrong, and has by its performance shown that it is not. The columns are of Phoenix section, but stronger than the section designed by the author. The foundations and their attachment to the columns are much better calculated to resist bending strains on the columns, and as there are none it is perfectly proper to stop the columns at the bases of the cross-girders. That they are none the worse for this is evident from the fact that there is no perceptible vibration for approaching trains, whatever may be the case elsewhere. The Second Avenue girders have "no connecting plates between the diagonals and chords," and have fewer rivets than the author believes to be proper, but it is a matter of fact that after seventeen years' service under a heavy traffic there are few or no loose rivets.

By the courtesy of Mr. Fransioli, General Manager, and Mr. Waterhouse, Chief Engineer of the Manhattan Elevated, the speaker was able to give the following interesting statistics as to the Second Avenue structure:

Age, 17 years. Length, 7.4 miles. Total cost of repairs to structure, not including track and painting, $40,613.23; per year, $2,390; per mile per year, $319. Cost of repairs per ton of structural iron in 17 years, $1.39, which is about 2 per cent. of the original cost. The total tonnage passing over this structure in 17 years is 252,356,693 tons.

Practical men would call this good design and good construction, however it may be criticised.

The expansion joints and the entire floor system of the Second Avenue structure have been closely imitated by the author, and the speaker was able to agree with him so far. He also agreed with the author where he says that holes in riveted work should be punched smaller than the diameter of rivets, and reamed to a greater diameter. Either this or drilling is essential to first-class work. The speaker specifies it himself for swing-bridges and long spans. Whether it should be insisted upon for elevated railway work he has some doubts; it would, perhaps, be better to put the extra cost of reaming into increased quantity of metal.

The Second Avenue structure was not reamed, but it is unusually massive. Its weight per foot for two tracks, the posts and cross girders being designed for four, is equal to that of the author's four-track structures. It is believed that its durability is due in a great measure to the low strains and large areas of metal, as well as good workmanship.

By William W. Crehore, Assoc. M. Am. Soc. C. E.

The author's statement as to the importance of good details and workmanship in elevated railroad structures is certainly commendable. There may be honest differences of opinion among engineers as to the comparative merits of two or more styles of detail to perform a given duty, but there are certain well-recognized principles which have been proved by experiments and experience to be fundamental in connecting and detailing the parts of a structure so that the full strength of each member is available when needed. That these principles either were not thoroughly understood or were not deemed of sufficient importance by the builders of elevated railroads ten or twenty years ago is very much in evidence in New York. The speaker had no more intimate knowledge of the Manhattan Elevated structure's condition than any one may obtain by riding over it or looking at it from the street, but enough is evident to show that the structure could be very much improved upon if rebuilt. Although the rolling stock now used is no heavier than was provided for by the designers, yet the live load is now a maximum, the wear and tear is continuous, and the speed of trains has been much increased, notably on curves. Then, too, the improvements in the air brake during the last fifteen years have caused a substantial increase in the traction load. It was the opinion of the speaker that under these conditions no amount of patching can prevent a gradual decline in the factor of safety of the structure, and without wishing to arouse any undue apprehension, one might reasonably seek to know why, in a city that gives special attention to all other building construction, whose insurance companies inspect carefully and regularly the elevators in the tall buildings, and whose vigilance for the health and safety of the people is so practical and thorough in other directions, the elevated railroad structure which carries 500,000 people a day should be left, with no check except the occasional superficial inspection of the State Railroad Commissioners, entirely to the watchfulness of its own management, which in other matters is known to be not too particular.

It will be argued and figures might be produced to show that the elevated railroads in New York have been remarkably free from accidents, having carried an enormous traffic during the last twenty years with practically absolute safety; all of which is true, being due partly to the very efficient handling of trains, and partly to the fact that the factor of safety of the structure is not yet used up. A chain is no stronger than its weakest link; the factor of safety of a structure is no greater than that of its weakest member or its weakest detail. A structure which is subjected to continual vibration and is never painted must of necessity be wearing out. It therefore becomes a matter of great interest to all who are directly concerned to know how nearly worn out the individual members and details of the Manhattan Elevated Railroad structure are.

CORRESPONDENCE.

By G. Bouscaren, M. Am. Soc. C. E.

Two points are brought out by the author which are specially worthy of discussion, viz., the selection of the grade of steel most appropriate to the class of structure under consideration and the desirability of a more extensive application of reaming in riveted work.

The denomination of medium steel generally implies a degree of hardness consistent with an ultimate strength of from 60,000 to 70,000 pounds per square inch, with a ductility measured by an elongation of about 25 per cent. in 8 inches. The corresponding figures for soft steel are generally from 50,000 to 60,000 pounds per square inch, and about 30 per cent. elongation.

Soft steel is a material eminently tough and ductile, the progress made in its manufacture leaves little to be desired in regard to uniformity in the qualities of products, and commands confidence in its ability to resist a considerable amount of rough treatment. It is manifestly superior to iron in most respects, and is rapidly taking its place in ship building and boiler making; it is without question well adapted to structures exposed to considerable vibration and impact, such as the deck members of railroad bridges in general, and all members of short-span elevated railroads in particular. The same degree of uniformity in quality cannot be claimed for medium steel at the present time; it may be obtained occasionally, but never with the same degree of certainty. Besides being a harder and less ductile material, medium steel is liable to extra hardness and brittleness in spots. Until it can be treated on the same footing as soft steel in point of uniformity, its use in the riveted members where exposed to sudden variations of stress, or to shocks incident to derailments or collision, will not afford the same degree of security as that of the softer metal. The examination of a railroad bridge fallen under a passenger train, presumably by the work of wreckers, has recently confirmed the writer in his views as to the use of medium steel in deck members. A notable feature of the wreck was a 60-foot steel plate girder standing almost vertical with one end about 3 feet in the ground. The only apparent injury to the girder besides the bent lateral angles at the end was in the bottom flanges, two of the four flange angles being cracked squarely across without any other deformation.

Steel of good quality is made by both the acid and basic process; the only marked point of difference seems to be that a lower content in phosphorus is practicable for basic steel than is the case for acid steel. Phosphorus being admittedly an objectionable element in steel, this consideration should seem to settle the question in favor of basic steel.

The writer is in hearty accord with the author in what he says in regard to the desirability of reaming rivet holes in all kinds of material. It is a universal practice to specify that all rivet holes should match exactly and be of the exact diameter required for the hot rivets. There is no difference of opinion as to the importance of these conditions to the good quality of the work. Every one knows that they cannot be secured without reaming, yet the stipulation as to reaming is generally omitted to save cost. It seems to be one of those instances of puerile self-deception where the engineer, unconsciously, perhaps, seeks to obtain a certain desirable result without paying for it. It is hardly necessary to add that such attempts are generally failures. Every one will also admit that punching is a brutal operation, which seriously injures the metal, be it iron or steel, within a certain distance from the shearing surface. If flaws are objectionable in the body of a plate, they certainly are more so in the bearing surfaces through which all stresses are transmitted. Under the old assumption attributing the resistance of a riveted joint to the friction between the plates, developed by the contraction of the rivets, it was a matter of little importance whether the rivets completely filled the holes or not, and punched holes answered the purpose well enough, but they are inconsistent with modern practice, where rivets are treated as pins.

The superiority of reamed work is no longer a matter for speculation. Carefully made tests at the Watertown Arsenal as far back as 1882 showed that it could be depended upon for a gain in strength of about 15 per cent. This result has been repeatedly confirmed by later experiments. As the matter now stands, it is simply a question between good work and inferior work, and whether the extra cost of reaming is worth the additional security implied in the greater strength and uniformity of the work. These advantages acquire a special importance in short spans and decks of railroad bridges.

The use of Portland cement in the concrete for the substructure is a wise provision, especially for the upper part of the pedestals exposed to severe stresses and weather.

In view of the fact that the columns are expected to act as cantilevers anchored to the pedestals, and to resist by bending all horizontal forces arising from curvature, from the wind, and from changes of temperature, it would be interesting to know the maximum degree of temperature, the wind pressure assumed per square foot, the speed of trains assumed on curves, the maximum range of temperature from the initial position where there is no temperature stress, and whether any provision is made for easements at the ends of curves. If such provision is not made, a considerable percentage should be added to the centrifugal force for impact. It would also be of interest to know the units of working stress adopted for the different parts of the structure, and in particular for the columns with the combination of all forces acting together.

By H. H. Rousseau, Jun. Am. Soc. C. E.

In regard to the reaming of holes for shop rivets in soft or even medium steel, the writer believes that due consideration should be given to the average number of component pieces the rivets pass through, to the amount of wear and tear the structure has to withstand, and to the financial resources of the purchaser, before arriving at a decision in any particular case. If the benefit of removing, by reaming, material possibly injured is waived, the question becomes reduced to ensuring sufficient bearing area for the rivets in the most economical, and at the same time a satisfactory, manner. The proposition is not that rivets in unreamed holes have no value, but what is a safe and proper value to give them. The question is not one of vital importance to the safety and stability of the structure, being only to establish the comparative value of a rivet driven in a reamed hole $\frac{1}{16}$ inch larger than the cold rivet, and one driven in a punched hole, the mean diameter of which, according to general practice, is $\frac{3}{32}$ inches larger than the diameter of the cold rivet. Justly or unjustly, no distinction is now made between the two, and, at present, the purchaser has only a choice between unreamed work, which is condemned on account of the deviation of punching from mathematical precision, and upheld on account of its cheapness, and the reamed work of admittedly superior workmanship and higher cost, the rivet values being taken the same for both. If a relation can be once established between the two, then by decreasing the number of rivets for reamed work, the two classes of work will be put more nearly on the same plane, as far as theoretical requirements and cost are concerned. It is of interest to determine what this will amount to on a 50-foot deck plate-girder span weighing 14 tons, and costing, reamed, $60 per ton erected. The number of rivets in the span will be taken as follows:

Flange angles to web	925
Flange angles to cover plates	925
Stiffeners and web splice	400
Bed plates	50
Lateral bracing	300
Total	2,600

At $3 per ton, the average price given by the author, reaming costs $42, about 1.6 cents per rivet. Any change in rivet values would affect appreciably only the number of rivets in the flange angles, and for the change in total shop cost caused by a rivet more or less may be taken the cost of material plus laying off and punching, and driving the rivet. At 5 cents per rivet, 840 additional rivets could be driven before the cost of reaming would be equaled, and in one-third the time it would take to ream, and it would thus not be economical to ream unless a rivet in punched work was worth less than about three-fourths a rivet in reamed work. The area of a $\frac{7}{8}$ inch rivet upset to $\frac{31}{32}$ inch, as in punched work, is increased over 20 per cent., which excess is not considered in order to be on the side of safety. For a $\frac{7}{8}$ inch rivet upset to $\frac{15}{16}$ inch in a reamed hole, there is less reason for disregarding the increased area of 14.8 per cent. Increasing the unit strain in proportion will cause a saving of 240 rivets in the flanges, which, at 6.6 cents, amounts to $16, over one-third of the cost of reaming. This may be stated as follows:

	Cost.	Per cent.
Punched work........................	$798.00	100
Reamed work, with increased rivet value.	824.00	103.3
Reamed work, with ordinary rivet value..	840.00	105.3

What is wanted at present is to know how long reaming lengthens the life of a structure or decreases its cost of maintenance. A practical experiment of the matter could be made on any railroad bridge having a number of spans of equal length, some spans being reamed and others punched, and by comparing results. The opinion is ventured that in general if the cost of a structure were to be increased 5 per cent., better results would be obtained by expending this amount on more material than for reaming. To those who are not in favor of reaming, the objection is not that reaming is not a good thing in itself, but that it is not worth, to the ordinary purchaser, in prolonging the life and increasing the efficiency of the structure, what he has to pay for it.

By Horace E. Horton, M. Am. Soc. C. E.

As to metal, material, and workmanship for elevated railroads, the writer does not understand the requirements are essentially different than for bridge work in general. It is interesting to note the modification in the ultimate strength of metal specified and used over a term of years. Thirty years ago iron of over 60,000 pounds tensile strength was demanded; however, iron of 48,000 pounds tensile strength was the accepted standard when iron went out of use for structures. Steel first used in structures was of 150,000 pounds tensile strength; later, 80,000 pounds seemed to be the favorite, and now the author shows the exact percentage of advantage in the use of 64,000-pound steel. What is to be the ultimate strength demanded for structural steel in the future can only be a matter of conjecture, but the writer thinks it reasonable to conclude that within a short period steel for structural work will be demanded of under 56,000 pounds tensile strength.

While in the past steel makers have not been prepared to furnish steel of this character, and it now can only be had at increased expense, indications are that this extra cost will be modified or eliminated at an early day.

No one at this time will offer to use 150,000-pound steel, and it is difficult to find an engineer who would justify himself in using three-quarters the bulk of 80,000-pound he would of 60,000-pound steel to accomplish a definite result. The author uses 7 per cent. less material of medium steel than he would of mild steel, and nearly offsets the estimated advantage by increased cost of manufacture. If his estimate is modified to fit the market as it is at this time, that is, manufactured structural material, f. o. b. Chicago at 2 cents instead of 3 cents per pound, as he indicates, his estimate of the cost of reaming would be from 5 to 10 per cent., or an average of 7½ per cent., somewhat in excess of the advantage named for extra strength.

The writer does not believe any such objection exists in the minds of manufacturers to reaming as indicated by the author. That they are not fully advised as to the exact cost is undoubtedly the fact. Whether it is $2 per ton, the minimum named, or $7, the maximum asked, has not been proved. Further, the manufacturer finds himself at a loss in tendering on work which demands reaming, to judge whether it is to be accompanied by mental science process or by physical act. While reaming has been specified for most steel bridge work for the past fifteen years, many of the manufacturing concerns of the country are in shape to do reaming only by the method which the author terms "humbug," while others are prepared to ream with drills from one-tenth to one-fifth the capacity of their rivet shops; hence, the conclusion is irresistible that a very large percentage of the reaming previously specified has been accomplished by an incantation pronounced over the punching machine.

The author proposes to ream rivet holes $\frac{3}{16}$ inch, that is, $\frac{3}{32}$ inch on each side of the hole, as a remedy for misfits of $\frac{4}{32}$ inch named as common in punched work. Evidently he has been unfortunate in his acquaintance, and further seems to overlook the fact that a concern which has rivet holes misfit by ⅛ inch will do slovenly work even when reamed. The writer's observation leads him to conclude that the punching of rivet holes and the driving of rivets is not more careless than much criticism. He has never seen a rivet go loose in service where the design was rational and there was any reason to expect satisfactory results from the rivet, and further diligent inquiry among those whose observation has been the broadest verifies his experience as stated.

The reaming of rivet holes in metal-work in the future must depend on the disposition of the proprietorship to pay for such reaming. The case where the ownership, as described in the paper, was ready to pay for reaming, in fact, insisted on having it done, turns on the further fact that the ownership was advised by its engineer that less reamed material would furnish a more valuable structure at less aggregate cost. It would be more instructive if there was an example of where proprietorship had shown a readiness to pay for the extra cost of reaming, where the extra cost would be 7½ per cent. of the value of the manufactured material, and the advantage lies only in an improvement in the feelings of the engineer. Examples of this character would at once remove all objection on the part of manufacturers to reaming, but when the argument is based on building a better structure with a smaller quantity of less reliable material, the writer believes proprietors, manufacturers and engineers all have reason to be sceptical, and he doubts if practice will follow the suggestion.

There are at this time three elevated roads operating in the city of Chicago, all of recent construction. Two of them have been reorganized, and the third is in the hands of a receiver. A fourth has considerable work of construction done, and the daily press states that it is negotiating for funds to carry the enterprise to completion. All have to meet the competition of well-equipped cable and electric street car lines as well as surface railroads, all of which competition would naturally point to the construction of elevated lines in shape to serve their patrons with the least discomfort, placing their cars as near the street grade as possible.

The author shows a structure with an elevation above street surface at the base of the rail of 21 feet, which is essentially the elevation of the roads built and projected, while the city requires a clearance of 14 feet. This makes it possible to use an elevation of 15 feet to the base of the rail; that is, the entire system of Chicago is built 6 feet higher to the base of the rail than the requirements of the city call for, while three of the four lines projected and built are largely on private right of way. The extra expense of building through bridges for street and alley crossings would have been balanced by the decreased cost of construction of the other parts of the line, while such parts of the line as have been built in the street would have been either through construction or carried on single columns on the curb line, where girders could have been placed under the rails. This would require modification of ordinance, and be attended undoubtedly with some difficulty, but it would be not at all impossible. Further, curves and intersections in the streets would be attended with greater difficulty than by the present method of construction, as undoubtedly many cases would develop where the tracks would have to be suspended from overhead girders.

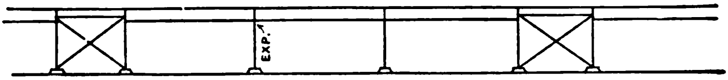
It is also apparent the floor of car might readily be 3 feet from the base of the rail instead of 4 feet. Thus the elevated structure would fulfil the demands of the city for a clearance of 14 feet and be only 18 feet to the floor of the car, instead of 25 feet. How much of the financial distress, past, present and to come, the useless 7-foot elevation has and is to cause is entirely a matter of speculation. It surely requires energy on the part of the patrons of the road to overcome it. It cannot be demonstrated that the elevated structures would have been a great financial success if 7 feet lower. That they would have had a more nearly even chance is obvious.

By O. E. Mogensen, Assoc. M. Am. Soc. C. E.

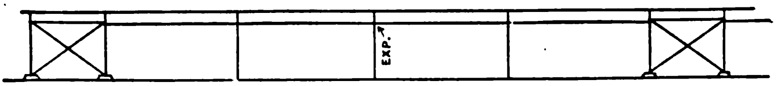
An elevated railroad presents in its general character and in its manner of construction more uniformity than most steel structures, as the single members and typical details once adopted are to appear over and over again throughout the work. Hence a thorough and detailed study, such as has been made by the author, is of great importance in order to obtain the strictest economy in construction, manufacture, and maintenance without sacrificing strength and rigidity in design. That the preliminary work had been successfully carried out by the author, and that every detail had been carefully considered when the contract was let, is shown by the fact that the last portion of the structure now erected, as well as the first, stands as a true copy of the typical drawings on which the contract price was based, and from which the cuts are reproduced.

This is evident from the fact that only one alteration, even of minor importance, was made in the lateral bracing, which originally was designed as shown in Fig. 2.

From this general plan it will be seen that the longitudinal thrust from the girders is carried into the columns by a triangular bracing on both sides of each column. This was necessary in order to avoid the horizontal bending in the top and bottom flanges of the cross girders due to temperature stresses. However, in detailing the cross girders the section adopted for the flange angles was found to be sufficient to carry the horizontal bending plus the strain due to the maximum live and dead load on the structure, for cross girders spaced but one span length from the tower bents. The bracing was, therefore, changed as shown in Fig. 32, thereby simplifying the manufacture and the field-work on the columns.



LAY-OUT FOR BRACING, TOWERS 3 SPANS APART.



LAY-OUT FOR BRACING, TOWERS 4 SPANS APART.

FIG. 32.

It should be noted in this connection that the omission of the triangular bracing was made only in structures on tangents, whereas the structure on curves remained as shown in Fig. 2, with additional lower lateral bracing, as mentioned by the author in Sec. XX.

In speaking of the riveting of work punched to full size, the author condemns the use of the movable air reamer used to enlarge eccentric rivet holes. In this connection the writer would state that it is a well-known fact among inspectors that less loose rivets are encountered in work punched to full size than in reamed or drilled work. This may be explained by the fact that the looseness of rivets driven through an irregular hole is much more difficult to detect than loose rivets driven through a perfect, cylindrical and smooth hole, as the crooked rivet naturally gives much greater friction to the irregular surface formed by the eccentric holes.

This is another good reason which speaks for the sub-punching and reaming or drilling in main members of structural work; whereas, punching to full size, when carefully done, will, in the writer's opinion, suffice for light work and for members of secondary importance.

The full value of sub-punching and reaming rivet holes in preference to punching to full size is somewhat impaired by the fact that the adjoining plates in long members may not come in tight contact with each other at the rivet holes. It is not seldom found that these voids are wide enough to allow the blade of a pocket-knife to pass between the plates close to the rivet. These voids are caused by the drilling. When the tool has passed through one plate and commences to pierce the other, the two plates spread enough to permit the steel shavings to locate between the plates around the rivet to a distance of 3 inches from its center. The removal of such shavings is a very simple matter, which would hardly necessitate the loosening of the bolts, but which should be done in order to derive the full benefit of the reaming or drilling of rivet holes.

Among the various designs so thoroughly discussed by the author, a comparison between steel and wooden floor systems has not been taken into consideration. As the Northwestern Elevated Railroad, with the exception of a small portion of the line, occupies private property, it is hardly probable that any city restrictions would have excluded the use of a steel floor system, which for several reasons seems of advantage for a structure built so substantially and for which, without doubt, greater economy in maintenance and durability during operation have been considered of more importance than an imaginary saving in the first cost.

The extra cost of a corrugated floor above that of a wooden floor system of vulcanized timber is justified by the following advantages:

FIRST.—When properly designed it will last as long as the main members in the structure.

SECOND.—As a lateral system it will increase the rigidity of the structure materially, and thus take the place of the upper lateral system, which is needed for the wooden floor system.

THIRD.—In case of fire from any of the adjacent buildings, destruction to the structure and interruption of the traffic might be avoided.

FOURTH.—Cost of maintenance and inspection is considerably lower than that of a wooden floor system so heavily loaded.

FIFTH.—Fifteen, thirty, or forty-five years hence, yellow pine or equally good timber may not be had for the market price quoted to-day.

In using a corrugated floor the longitudinal girders may be raised far enough above the top flanges of the cross-girders to act as guard rails, which would necessitate a spacing of about 7 feet 2 inches center to center of the longitudinal girders.

The first cost of such a floor stands as about $11.10 per linear foot of structure to $6.28 per linear foot of structure for the wooden floor system, based on the price of $38 per 1,000 feet B. M. for vulcanized timber in place, as quoted by the author. This would mean an extra cost of about 15 per cent. to be added to the total cost of the line, which is quoted as $32.65 per linear foot of line for Design 6.

If the life of the vulcanized timber be put at fifteen years, these figures show that in less than twenty-seven years the money expended for a wooden floor system would amount to the same as the entire cost of the steel floor, disregarding the greater cost for inspection and maintenance of the wooden floor system. It may be said that the steel floor directly supporting the rail would cause greater vibrations, noise and wear upon the structure than the wooden floor system. But has not the experience of recent years demonstrated the superiority of the steel floor system over the wooden floor system, which needs constant attention after a service of four to five years, which attention is especially dangerous on an electric elevated railroad, operated by the third-rail system?

By Wm. M. Hall, M. Am. Soc. C. E.

The author's specification for fineness provides that 90 per cent. shall pass the No. 100 sieve. It is believed that most of the foreign Portlands will not pass this specification, although they are equal or superior to the best domestic makes. It would, therefore, be interesting to know if the foreign makes were excluded by this specification, or if the manufacturers shipped, or proposed shipping, cargoes of especially fine ground cement to meet the requirements. The specification for tensile strength appears to give a maximum as well as a minimum limit. The minimum in all cases is very low. Most specifications give only the minimum tensile strength, which, for briquettes treated as specified, is now usually placed between the figures following, viz.:

Pure cement......	7-day	briquettes,	between	400	and	500	pounds.
"	28 "	"	"	475	"	600	"
1 cement, 3 sand...	7 "	"	"	120	"	180	"
1 " 3 " ...	28 "	"	"	170	"	250	"

It has been considered not detrimental to a cement to show a higher tensile strength for short-time tests than any of the maxima given in the author's specifications, unless it was shown to recede later in strength. It is therefore, not clear to the writer why they are given.

In no part of these specifications is the temperature of air or water mentioned. The temperature of both, however, is an important factor in the time of setting, and also in all other tests. Therefore the writer believes that the temperature of water for mixing should be accurately specified, and the temperature of air in the testing room approximately so.

By J. C. Ostrup, Assoc. M. Am. Soc. C. E.

In comparing the merits of the many excellent designs presented in the paper, the writer will confine himself to those of Design 1, Fig. 12, and to Design 10, Fig. 21. Some of the more important advantages in Design 1 are found in the fact that the short transverse girder for each track and its bracket and column are made in one piece in the shop, and that the web plate through these parts is practically continuous; its cheapness, costing about $11,200 less per mile; its greater rigidity and facility of manufacture and erection. For these reasons this design was adopted for the Northwestern Elevated Railroad, but over this design, Design 10 has, in the writer's opinion, one material advantage. It will be seen in Fig. 9 that the short transverse girder projects 3⅝ inches, which, with the additional amount of projection caused by the rivet heads, is increased to about 4 inches, above the plane of the longitudinal girders. This feature is eliminated in Design 10, which would be a material advantage when placing the floor system or track work on the structure.

For various reasons, which are immaterial to this discussion, it is intended on all curves of the Northwestern Elevated Railroad and the Union Elevated Railroad to use beveled ties spaced 15 inches center to center, and to place them radially to the curves. Local conditions have in most cases rendered it impossible to place the bents or transverse girders radially, and their direction is therefore at variance with that intended for the crossties. Consequently, it will be necessary to change the direction of all ties in proximity to the cross girders, or to adze down the ties by 4 inches where they cross the top flange of the transverse girders, both of which methods are undesirable. Even supposing that all the cross girders could be located radially, the width of their top chord would, of necessity, caused by local conditions, vary from 10 to 14 inches. As the ties are 8 inches wide and spaced 15 inches center to center, this leaves a clear space of 7 inches between two adjacent cross-ties. This space of 7 inches would be anywhere from 10 to 14 inches at every bent, and produce an irregularity which is also undesirable.

In regard to the merits of the braced towers, the author seems to have shown some unnecessary modesty in not describing their great and undisputed advantages more fully. On all elevated roads the expansion pockets are generally spaced about 150 feet apart, with a clear opening in the pocket of from 2 to 4 inches, according to design and accuracy in the triangulation work, and, therefore, a structure of this kind forms a series of independent sections, each 150 feet in length. The chief object in view, when designing every detail of an elevated railroad expected to pay interest on its invested capital, should be rapid transportation. With the utmost universal use of electric power for the competing surface cars, its financial life depends almost solely upon this point. Therefore, it is necessary to propel a train over this non-continuous structure at a rate of say 40 miles an hour, and to start and to stop the train as quickly as the traction will permit. All this causes a great amount of vibration. The idea of properly checking this vibration, which is greatly detrimental to the rigidity as well as to the life of the structure, seems to have been almost entirely overlooked heretofore, and is solved excellently and effectively in Design 1. Another highly commendable point in favor of this feature is the fact that these braced towers reduce to a considerable extent the total weight of metal in the structure, which reduction, according to the author, amounts to the surprising figure of 9 per cent.

By C. E. H. Campbell, M. Am. Soc. C. E.

In the author's study of the elevated railroad question, it seems that he has almost exhausted the points of discussion himself by presenting some fourteen different designs and arrangements of structures, with comments thereon. As to the specifications and designs necessary for the construction of such structures, when certain requirements are fixed and conditions determined and the structural engineer takes hold of the case, the results are generally dependent on his knowledge and experience, assisted by information that he is able to collect from others who may be skilled in that line. The author seems to have pursued this method and reached out further by investigating defective features in existing structures, and such endeavors to remedy defects cannot fail to improve production, if the man who prescribes the remedy knows all about the disease.

The author dwells at some length on the matter of reaming. From the engineer's standpoint, where the nearest possible approach to perfection is desired, his deductions cannot be denied.

From the manufacturer's standpoint, objections will be in inverse proportion to his facilities for performing this class of work. The writer's opinion is that if any built member, whether in tension or compression, has assigned to it a fixed value of working stress per square inch, this fixed value is based upon the physical properties of solid, perfect and faultless material, and the joining together of the component parts of the member by rivets, bolts, welds, or any other method, should be so perfect in detail that there will be no defect in the member against which it is possible to provide. Punching acts in the nature of a force applied almost instantaneously, with power enough to tear or shear a hole through the metal. The part that is thus disrupted is torn, bent, bruised and evidently damaged for at least a small distance around the hole, and it is evident that those parts that are thus distorted cannot have the same effective strength per unit as the original sound piece. Further, if part of the rivet holes match and others do not, there must be an unequal straining of the particles of metal in the member, even if the rivets fill the holes fairly well. The writer has heard some manufacturers claim that if reaming is deemed necessary, then each piece can as well be reamed separately before assembling. This is evidently wrong, as the chance for bad matching of holes remains the same as before reaming. To produce perfect results, all component parts should be assembled before reaming. The results obtained by the use of portable reamers are somewhat questionable, depending to some extent on the intelligence of the workman handling the machine. The use of stationary reamers places results beyond question.

Regarding longitudinal bracing and the vibration incident to the lack of it, the writer had an opportunity to observe this defect in the Sioux City elevated road, some 6,000 feet in length, in which there was no provision whatever made for traction force, and dependence was placed only on the riveted connections between the ends of girders and columns. The vibration was plainly noticeable at a point 2,000 feet from the moving train. What effect this will have on the connecting rivets remains to be discovered.

The question of painting metal in such a way as to preserve it for any length of time from the action of the elements has been the subject of considerable talk, with but small results. The custom of oiling metal at shops or mills produces no good results, further than protection from rust during manufacture and transportation. Oil is a poor foundation on which to spread the paint. The protective element in paint is the pigment, and the oil the medium by which it is applied. Therefore, if anything is put on the metal at shops or mills, it should be the best protective compound known.

The author takes occasion to mention the frequent practice of some bidders of attempting to throw discredit on the plans and specifications of the consulting engineer. The writer ventured the opinion that he who knows all about the disease is qualified to prescribe the remedy. While the author has diagnosed the case in question, he has encountered another kind of disease. This malady often gets a grip on engineers and proprietors of some manufacturing concerns, and they determine that the consulting engineer does not know what his employers want, but that they do. Therefore they attempt to ignore the engineer's designs by submitting "much superior" ones of their own special make. Such designs are generally made to conform to their individual shop practice and the most economical shapes rolled by their own mill, and the only object in view is cheapening the product to the manufacturer, and obtaining contracts with more profit than if taken on the engineer's specifications.

By Frank C. Osborn, M. Am. Soc. C. E.

The writer takes pleasure in heartily indorsing the paper, as a whole, but would like to call attention to a few points mentioned by the author, with the idea of emphasizing them. The first of these is the requirement in regard to providing "adequate means of transmitting the thrust of braked trains from longitudinal girders to columns without overstraining the cross girders," and the proportioning of columns to "provide sufficient strength to resist direct load, bending from longitudinal thrust, bending from transverse thrust, and on curves bending from centrifugal loads." These features of design have frequently been lost sight of entirely, and their importance ought to be recognized fully, for the reason that the stresses requiring these provisions occur at every passage of a train. It should be borne in mind that any stress applied to such structures must eventually reach the earth, and proper provision ought, of course, to be made for its doing so.

In regard to the importance of good design, material and workmanship for elevated railroads, it seems that these requirements are, if anything, even more important than for ordinary steam railroad bridges, for the reason that trains are much more frequent, and they are being constantly stopped and started at stations which are comparatively short distances apart, making the punishment to which an elevated railway is subjected much more severe than that of an ordinary railway bridge.

The writer agrees with the author in the preference for medium steel with sub-punching and reaming over soft steel without the reaming. A gain is effected on account of the greater strength of the medium steel, and the reaming is certainly advisable, as it removes the injured metal in the immediate vicinity of the hole and makes a better job from a workmanship standpoint. Objections to reaming and drilling appear to come principally from manufacturers operating small plants without facilities for doing this kind of work. Some manufacturers, however, although fully equipped to do the work, are in the habit of bidding on work for which reaming is specified and then doing their utmost to have the reaming waived, solely with the view of increasing their profit. The practice of a number of manufacturers of always endeavoring to have modifications and changes made in plans and specifications and solely with the idea of diminishing the cost of the work to themselves, without any advantages whatever to the purchaser, is one hardly to be recommended. This policy, in a number of cases known to the writer, has led to the placing of the contractor at a positive disadvantage on subsequent work.

In regard to faulty details, that of connecting members together by riveted joints without paying due attention to the proper intersection of gravity lines is probably as common as any. The only excuse for it ordinarily is the saving of a very small amount of material in the gusset plates.

The writer fully agrees with the author regarding the attachment of cross girders to columns. This connection should be as rigid as practicable, and this can best be accomplished by running the column up to the top of the cross girder and riveting the two together thoroughly.

It is the opinion of the writer that what is known as carbon primer is superior to linseed oil for a first coat for structural iron or steel. It is thin, flows readily, and unites firmly to the metal. It dries hard and does not give the greasy surface to metal that linseed oil does. It makes a finish to the metal surface that permits the laying out of work as readily as upon the raw material. The carbon primer should be applied as soon as practicable after rolling, and certainly before any tendency to rust appears.

As to the aesthetics of structural steel designing, it is certainly time that engineers gave serious attention to this point. For the ordinary railway structure, architectural appearance is not particularly important, as but few people have occasion to view it. For city or suburban bridges, however, and particularly for elevated railways, the question of appearance is a live one and well worth careful study and consideration by engineers. An engineer as well as an architect owes it to the general public to give a structure satisfactory not only from a utilitarian standpoint, but from an artistic standpoint also. This artistic effect is not necessarily obtained by elaborate ornamentation, in fact too much or inappropriate ornamentation may be worse than none at all. The desired effect may frequently be obtained by a proper and careful study of the principal lines and form of the main structure. A structure may have little or nothing of pure ornamentation and yet be very pleasing to the eye on account of its natural grace and apparent adaptability to the purpose for which designed. Engineers, as a rule, give too little attention to the architectural effect of their structures, and they will doubtless concede that the author has made a distinct and satisfactory advance over what has heretofore been done in this direction by American engineers.

By Wm. Arthur Pratt, M. Am. Soc. C. E.

The writer has had experience only with elevated viaducts designed for the heavy loads of ordinary steam roads. The conditions are different in the case of rapid transit lines in city streets, whether the motive power be electricity or steam, but the traffic is no less constant than in case of the heavier structures. To one who has had to do with the construction and maintenance of these viaducts, several facts are very apparent:

First.—The service is extremely severe, especially on those viaducts forming approaches to important trunk line terminals.

Second.—The deterioration of the structure is much more rapid than in the case of equally well designed work of other types on other parts of the line.

Third.—The foundations require most careful treatment in design and construction, and frequently show settlement, and require more or less extensive repairs before the superstructure develops any weakness.

The writer therefore holds that minimum first cost is not necessarily synonymous with true economy, and that the use of medium steel with high unit stresses, thereby reducing weight and increasing deflections, is a move in the wrong direction. The writer believes from a careful observation of the behavior of many viaducts in actual service that the most durable and satisfactory are those very heavy structures with solid trough floors and stone-ballasted roadways. While this latter style of construction is probably not available for a rapid-transit elevated railway built in the streets of a city, the engineer can at least use comparatively low unit stresses, thereby reducing deflections to a minimum and providing additional mass to absorb the impact of the moving load. If low unit stresses are used, there remains no imperative reason for using medium steel, as the ultimate strength and elastic limit of the material are no longer in question; and if soft steel is used, the writer sees no reason for a general reaming specification, as his experience shows conclusively that there are several bridge shops in the country which can turn out punched work with an accuracy leaving but little room for criticism.

The author's figures are very seductive, but the writer is by no means convinced thereby that the four-column bent is the best arrangement for a four-track viaduct. The reason for this lack of faith is in what has been previously said about the uncertainty of foundations under viaduct columns. As a case in point the following testimony is submitted. The facts pertain to a viaduct for which the writer provided the superstructure.

Foundation beds, good, compact gravel. Lower course of masonry, concrete 11 feet square, 3 feet thick. Balance of foundation, heavy, undressed ashlar in regular courses. Caps, sandstone, 42 inches square, 20 inches thick, four anchor bolts in each foundation. Maximum load, 250 tons, of which about 140 tons is live load. Pressure on foundation beds, about 2 tons per square foot.

About 100 of these foundations were built, all of substantially the same character, the beds being apparently of the same good material throughout. After five years' service, 60 per cent. of these foundations showed settlements varying from 1 to 3 inches, and of the remainder almost all showed an appreciable settlement.

Additional testimony could be furnished if necessary, but the tenor of it would not differ from the preceding. The writer therefore believes that having determined upon a satisfactory span-length, it is good practice to reduce the number of column foundations to a minimum, using not more than two in a bent, unless other conditions require a modification of this arrangement. This reduces to a minimum the number of points liable to settlement, and the consequent distortion of the structure becomes a less serious question. The liability to settlement of foundations leads the writer to believe also that wherever physical conditions will permit, it is better practice to design the structure with the longitudinal girders carried on the upper flanges of the cross girders, rather than riveted to the webs of the latter. In case of unequal settlement of adjacent bents, the latter detail would involve severe and possibly destructive strains in the header connections; while but small harm would be done if the track girders were simply seated on top of the cross-girders.

The author believes that a shop coat of boiled linseed oil on finished members is all that is required before erection, and this is also the present practice of the Pennsylvania Railroad Company. Some recent developments in connection with the bridge work of this company have led the writer to believe that this practice is not good. An order of plate girders with ⅞-inch rivets passed the shop inspection before the oil coat was applied, and the riveting was fully up to the high standard of the shop which furnished the girders. After the delivery of the work and during the erection, the railroad company's men discovered that far too large a percentage of the rivets was loose, and this led to a careful investigation with experimental pieces which were riveted up and tested for loose rivets before and after oiling. The fact was developed that rivets which were tight before oiling could in most cases be readily loosened with an inspector's hammer after the oil had penetrated around the shank of the rivet. The effect of the oil was to soften the scale on the surface of the rivet, at the same time reducing the friction of the rivet heads like any other lubricant. The test pieces were then cut through the center lines of the rivets and showed that the upsetting had been practically perfect. The experiments therefore seemed to show that while many of the rivets would have been condemned by an inspection after the oil was applied, the situation could not have been improved by cutting out and replacing these rivets. In the writer's judgment the above facts are a possible explanation of the comparatively large number of loose rivets which occasionally appear in certain girder spans that give no indication of poor work during the shop inspection. If the girders were placed in service while the oil was still fresh, they were subjected to substantially the same conditions as were the experimental pieces which were tested after oiling. In the writer's opinion it is better to give the finished pieces a heavy priming coat of some approved paint in the shop than to use linseed oil alone.

By A. P. Boller, M. Am. Soc. C. E.

In discussing a paper like the author's elaborate examination of the problems involved in the construction of elevated railroads, it is impossible within reasonable limits to comment on all the points he takes up. In his sweeping condemnation of all past efforts in this direction, he seems to have forgotten all modern work is a development of the past, and his own excellent work would not have been possible except for the labors of those before him. In the early days of such roads, the science of constructive engineering was only taking shape in this country. The problems involved, as they are now seen, are not complicated, unless one chooses to make them so. The construction is simply a continuous line of girders supported on columns resting on pedestals arranged, as to span and support, according to the local requirements of any given case, and an economical balancing of spans and supports as near as it is practicable to do so, subordinate to the necessities of street traffic. The constructive details necessitated thereby are a matter of the individual taste of the designer, so long as they are controlled by principles of statics and the laws of the strength of materials used, coupled with a full knowledge of shop methods and facilities.

Such structures are not subject to any architectural treatment whatever, and should be built as unobtrusively as possible. The writer prefers plate girder work to lattice work, as it can be made shallower, even at the expense of a little more flange material. For straight-away work, he has always thought the type of the Third Avenue line in New York City, of course detailed with modern ideas, was about the best for a wide avenue, where posts could be put in the avenue, being the least obtrusive. For a narrow street, or where otherwise required, of course there is nothing left but to put columns inside the curb line and girder across the street.

As to pedestals he believes monoliths of well made concrete are the best, and that the specifications for cement in the paper are eminently sensible, and calculated to produce good results. He is prejudiced possibly in favoring natural stone for cap stones, although the author seems to have obtained satisfactory results with artificial granolithic stone. The author lays great stress on his manner of bolting his column to the pedestal, but in an ordinary standard pedestal there is the weight of a comparatively small volume of material above the anchor washers, and were there anywhere near the strain on the bolts he imagines, it would have told long since on some of the pedestals of the New York and Brooklyn roads. This idea of pull on the bolts he has derived from an assumption that 20 per cent. of the live load between two adjacent expansion points acts as a horizontal thrust. So far as the writer knows there are no exact data on this subject, but he does not believe it is anywhere near that figure. The rails, guards, etc., are continuous, and distribute what thrust there is over a long distance. The author would ignore this part of the structure as a distributing factor, and go to much trouble and expense to make the structure entirely independent of it. The rails and guards exist, and will do their distributing work, whatever it is, and why ignore them? Many years ago, when the original Greenwich Street line in New York was running, this question came up, and the late Milton Courtwright, M. Am. Soc. C. E., made some experiments as to the effect of braking trains on this, the flimsiest structure ever built for elevated railway purposes. The writer does not know that these experiments were ever recorded, and doubts if they were made with any scientific refinement, but he remembers Mr. Courtwright telling him that whatever horizontal thrust the brakes produced was so small that it was a matter of no moment, and demanded no special provision.

Growing out of this fear of horizontal thrust, the author has evolved a column of heavy cross-section necessitating some complication of detail. His column is a good one, of course, but from magnified assumptions of stress, he has magnified his column beyond necessary requirements. The writer likes his idea of running the columns past the ends of the cross girders, instead of simply resting the girders on top of the columns, when posts are on sidewalks, also throwing in a strut between longitudinal girders and column head, as well as solid plate girder corner brackets. These add much to general stiffness, and such structures cannot be too stiff.

The author calls attention to rust conditions around the foot of planted columns, but just how this is to be avoided it is difficult to see. To carry up the capstone above the street surface sufficiently to remove the column above moisture is impracticable in most cases, on account of creating too much obstruction in the streets. His idea of filling the boxed space around the column foot with concrete amounts to little as a protection, as no concrete ever made is impervious to moisture, and it is impracticable to get intimate contact between concrete so placed and the detail of the metal-work. Presumably the only thing that can be done is, before concreting, to plaster the metal surface thoroughly with cement mortar, but even such mortar is only less permeable to moisture than the concrete. This matter is a serious one for all such constructions, and the writer knows of no way of getting rid of the difficulty. The nearest approach to protection is the column planted in a cast-iron pocket, the neck of the casting rising some inches above the plane of the roadway or sidewalk, the voids between columns and casting being well grouted with cement. The greater part of the New York elevated construction is of this character, but coupled with this form of construction is the difficulty or impossibility of getting solid contact between the post-end and the bottom of the cast socket, which cannot be faced. The writer would suggest in any case a thorough priming of the post foot with the best attainable primer, which will not corrode under moisture, and then asphalting with a good natural asphalt. In the darkness and under moisture the volatile oils in such asphalt will probably hold for an indefinite time. Asphalted rails in the tunnel of the Fourth Avenue improvement have lasted well; the same asphalt exposed to sunshine soon becomes powdery and useless.

As to the use of medium steel or soft steel, the writer is an advocate of the former as being perfectly reliable, of higher value and strainable to a higher unit. There is a tendency toward the use of soft steel, encouraged and promoted by the manufacturers, as the supply is abundant, and ease of manipulation in the shop makes it cheaper to work. The engineer is impressed with the arguments of the manufacturer that he is using a safer steel, and one that will better withstand shock. This is all from mercantile interest, for can any steel be subject to higher shocks than rails, connecting rods, driving wheels, etc., all of steel of very much higher carbon than any contemplated for constructive purposes, the very hardness of which gives it value against deformations. Steel must be treated and manipulated according to its quality and grade, and the nearer it approaches homogeneous iron, which so-called soft steel really is, the less expensive is it to work, and the more desirable for the shop.

The author is quite right in all he says about reaming. All first-class riveted work should be reamed if only for the purpose of truly matching holes, and perfect work can be attained only by reaming through all the parts assembled together. The use of a tapered and flexible reamer should not be allowed, except in some out-of-the-way place that a rigid drill cannot reach, but no prime joint or important connection should be designed so that the rivet holes are inaccessible. A concession for punched holes in soft steel might be made for gussets and secondary connections, but all direct connections, such as webs and flanges, should be reamed in any sort of steel adopted. Metal below ⅝ to ¾ inch in thickness may be sub-punched and reamed; above that thickness it should be drilled from the solid.

As to the choice between basic and acid steel, in these days there is not enough difference between them to warrant a preference, except perhaps for eyebars, where acid steel is the best, for the reason that the annealing of such bars causes such a drop in tensile strength from that shown by the initial steel, that as high a limit of ultimate strength steel should be used as is consistent with toughness and ductility. For this purpose acid steel, made as it is from the best quality of original stock, is the safest and best to use.

The author lays none too great stress on painting, but it does seem almost impossible to have this well done, particularly the vital priming in the shops. The writer does not think much, if anything, would be gained by oiling material in the rolling mill, as the author suggests, for there is much mill scale to come off during shop handling and manipulation, and such oil as remained would interfere with the primer getting in immediate contact with the metal. The best attainable primer should be employed, and it should be properly put on under cover, and dry before shipment. Most work is painted outside with extreme carelessness and shipped fresh, and between the cutting of cinders from the locomotives and the rubbing of pieces against each other, it reaches its destination in a condition no properly primed material should. As good priming is the essence of protecting metal against rust, engineers should exercise more care in the material they use, and see that it is properly put on under proper conditions. If economy is the order of the day, let it be exercised on the outer coatings. Manufacturers are not wholly to blame for sloppy shop painting, as time for completion of work is usually set at such a date that the strain to meet time expectations is intense, to meet which work must be shipped almost as soon as the last rivet is driven, and the shop priming is done on a sort of catch-as-catch-can principle. No work ought to be crowded quicker than it can be done rightly, and engineers, in so far as they can control, should see to it that the time exacted can be properly met.

The author's account of his letting, at which certain manufacturers tendered on other conditions than those asked for by the specifications gives an exhibition of practices entirely too common. In public works, the law compels the throwing out of such tenders as irregular, and it ought to be done in private lettings. It is eminently unfair to other bidders, and derogatory to the right relation between the engineer and contractor. It is highly impertinent in a manufacturer, when asked to tender under a certain specification, to ignore the requirements of the same, by bidding on a basis that better suits his own shop facilities, hoping to go over the engineer's head by attracting the buyer with a lower price. No self-respecting engineer should permit such an effort to succeed, and it is refreshing to see that the author stamped it out in his case. In making these remarks the writer does not wish to be understood as belittling the knowledge and experiences of the shops, for much of the marvelous advance in constructive engineering is due to them, fully as much, if not more, than has been contributed by the purely professional brethren. But the wise engineer will familiarize himself with shop facilities and experiences in details and methods of construction, which every shop accumulates in the course of a business career in contact with many minds, out of which he will edit, as it were, the best practice for his own particular work. The writer has not much respect for the engineer who tries to evolve everything from his own inner consciousness, oblivious of the many bright minds that have added to the wealth of experience and possibilities. The author has shown great familiarity with the best shop practices and modern ideas of designing, and he has gleaned well from past experience with an enviable industry that became crystallized in such an elevated railroad as he wanted to build. In the face of this, to have a contractor asked to bid upon that construction of road come forward and turn the engineer's plans down, endeavoring to substitute some of his own, for purely commercial reasons, advanced under cover of more or less technical speciousness, was a very high-handed proceeding. It is certainly a satisfaction to know that the parties fell into the pit which they dug for others. In this connection the writer wishes to remark that after a work is awarded, it is perfectly proper to favor the successful shop by such modification of details as may best suit the special facilities and conveniences of that shop, without sacrificing any general principles. An arbitrary adherence to a notion is not good business or sensible engineering.

The author concludes his paper with some remarks on the aesthetics of designing, with an architecturally treated road as he would like to build one. It is sincerely hoped he will not have the opportunity, for if the elementary principle of sound architecture "not to construct decoration but decorate construction" can be violated, it has been certainly accomplished in the design submitted. There is a homely old expression, that "you cannot make a silk purse out of a sow's ear," which fits here, for you cannot make an architectural (aesthetic) structure out of an elevated railroad, despite false arches, foliated column caps, or gargoyles on the ends of the brackets.

By A. A. Stuart, M. Am. Soc. C. E.

While the writer desires to go on record as approving most of the conclusions reached by the author in evolving the various details of construction described in the paper, yet there are some statements made and details employed which he feels are neither founded upon facts nor sustained by experience. The initial statement that methods heretofore employed in designing structures for elevated railways are radically wrong is rather too sweeping to be sustained by facts, nor is it justified by a careful examination of the designs presented by the author, since they do not differ in essential elements from recent designs employed in other cities where the limiting conditions were at all similar. There are differences in some of the details, but the relative merits of these are the subject for debate rather than the hasty judgment that any one is superior to all others. Such differences doubtless will always exist, and can well do so without subjecting any particular one to the charge of being radically wrong. The structure in Chicago chiefly treated by the author, being located on property owned or controlled by the railway company, made it possible to employ the braced-tower construction, which has never been applicable to the structures in either New York or Brooklyn, because they are located wholly in public streets. This feature constitutes the only radical difference between the author's design and the design of the structures built in New York or Brooklyn within the past few years, but its absence in the latter certainly does not warrant the statement or belief that their design is radically wrong.

As to the desirability of having all rivet holes precisely concentric in members to be united, there can be no question raised, but the writer's observation does not lead to the belief that the expense which would be entailed in securing this by the method suggested by the author would be justified. The use of riveted work in this country has been very extensive and covers a long period, but so far as the writer has been enabled to learn, the present methods of manufacture employed by the best shops have given satisfactory results under a large variation in service; hence any change in those methods involving so much additional expense does not appear to be warranted.

In the matter of Portland cement, the author's specifications are gravely inconsistent in that he exacts the best possible quality obtainable, while in the next paragraph a physical requirement is stated which the poorest cement in the market would fully satisfy. Indeed the wide latitude permitted in the tensile strength is of itself generally regarded as unfailing evidence of poor quality. The writer makes special reference to this here in the hope that it may at least serve in a small degree to eliminate such inconsistencies or ambiguous expressions from specifications, believing that they are the most fruitful source of contentions and disputes between engineer and contractor.

As to the track system presented by the author, it is almost identical with that used on the older roads in New York and Brooklyn, which has been much modified as a result of long experience on those roads. The writer has never been able to conceive of any adequate reason for using inner guard rails on straight track, but, on the other hand, will state what he believes to be several rational ones for omitting them. While it is possible for a derailment to occur on an unobstructed piece of straight elevated railway track, it is a very remote possibility when gauged by the fact that an experience of twenty-five years on the New York elevated railways furnishes no instance of such an occurrence. This fact alone would seem to deny the utility of these guards in averting calamity, the only purpose for which they are employed. Should a derailment occur, the question arises whether the outer guard rail does not offer ample security, if left to act alone, in preventing a truck from leaving the structure.

This is certainly true if the four guard rails are spaced, as in the author's design, so as to require each to act independently instead of in pairs. If inner guards are used at all, they should be so spaced that opposite wheels of a derailed truck would encounter an inner guard and the opposite outer one at the same instant, and neither guard should be laid so near the track rail as to prevent a derailed wheel from dropping into the space, except, of course, on curves. If the inner guards are never called upon to perform any service then their use is not justified, and they should be omitted for the reason that they add additional perishable material to be removed, and otherwise increase the cost of track maintenance by shutting out air and sunlight from the ties, thus hastening their decay, and they add much difficulty in making repairs to track rails and ties. It is a matter of much surprise to see the use of short hook bolts revived by the author, in view of the evident advantages possessed by the long hook bolt, which engages the flange of girder, tie and outer guard rail in one mechanical operation.

Referring to the use of treated timber in the track system, the author's conclusions, not being based upon facts developed by experience, are very misleading. It is not true that yellow pine or any other timber used for structural purposes becomes unfit for further service after 7½ years' use in elevated railway tracks, or even in surface tracks. A very large percentage of the timber laid in elevated railway tracks 12 or 15 years ago is still in service, and will so remain a number of years. The writer believes it to be a safe assertion that its average life is quite 15 years in such a situation, if not destroyed by mechanical means, assuming that reasonable care and judgment are employed in its selection. The largest number of renewals made within the first 10 or 12 years are rendered necessary by mechanical agents and not chemical ones. While it is true that the cost of labor for renewing a single tie averages about $1, it is not a fact that the largest percentage of timber would be renewed in this way, but in continuous sections, where the circumstances would reduce the cost of labor to a sum not much in excess of that required for laying new track. These facts would materially alter the author's conclusions if incorporated in his computations to ascertain the relative merits of treated and untreated timber.

From a theoretical standpoint, the author's criticism of the neglect to proportion all columns for resisting flexure is fully justified, but the writer has satisfied himself by careful observation that the assumptions usually made as to the magnitude or stresses which the columns will be called upon to resist are very much in error, else few or none of the structures in New York or Brooklyn would be standing at the present time. These structures themselves afford the best and most reliable evidence of their ability to resist safely both longitudinal and transverse stresses which are brought into the columns, and a careful observation of their behavior under conditions producing maximum stresses will fail to disclose any evidence whatever that they are excessively strained. The writer has seen and very carefully noted the conditions where the transverse girders were cut entirely loose from the columns over a distance of nearly a quarter of a mile, the structure being supported temporarily on 15 inch square timbers clamped to the remaining stubs of the iron columns, and while in this condition a three-minute interval train service was maintained over the structure, which is on a 2 per cent. grade, without producing any increased vibrations so far as could be detected.* It seems to the writer that, in addition to other interesting features involved in this work, it furnishes confirmatory evidence of a very pronounced character that the customary assumptions relative to lateral stresses in such structures are not substantiated by facts, and it is believed that much metal has been wasted in providing for stresses which appear to exist only in the imagination.

The cement finish used by the author to cap the concrete foundations has given very satisfactory results on Brooklyn roads during the past four years, but the writer does not believe that a mixture of one part cement to to three parts of crushed granite, as described by the author, will give satisfaction, either in the matter of finish or durability, since it is too porous to admit of good troweling and prevent disintegration by frost. Indeed, this mixture is no richer in cement than the concrete used in the body of the work below the frost line, where it is protected from abrasion and the unit pressure is very much less than immediately under the columns.

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*See Transactions, Vol. xxxii, p. 363.

By Albert A. Trocon, M. Am. Soc. C. E.

The author says that "there is no bridge shop in existence which can turn out truly first-class work without sub-punching and reaming or drilling." The writer thinks there are a great many shops that can do so, or rather, that all of them worthy of the name can, if the proper care is taken. The care required to do this is much less trouble than that caused by having to sub-punch and ream. The writer knows that in the shop with which he is connected, the punching is usually done so accurately that very little or practically no drifting is required. When the holes did not match, it was generally found to be the fault of the laying off, and in these cases reaming would have been of no avail, as the holes were too far apart to be remedied in that manner.

The idea that rivets cannot be driven so as to fill the holes completely when the latter are punched only, and they are left of slightly varying diameters, seems to the writer erroneous, especially where the rivets are machine driven, which is the universal method in bridge and structural work, except in the few places where they cannot be reached by a riveter. He has quite often seen specimens of riveted work, with holes punched only and not reamed, sawed through the center of the rivets, where they so completely filled the holes that it was difficult to distinguish the lines separating the rivets from the balance of the material. Some of these specimens contained five or six plates riveted together. The writer thinks that most manufacturers will concur in his views. If it is the case, then, that holes can be made to match so perfectly by punching without reaming that there will be no trouble in making the rivets enter into their places, what is the use of requiring manufacturers to sub-punch and ream (when punching alone does not injure the material), thereby causing an extra expense of from 0.1 to 0.25 cent per pound? The writer thinks it good practice to ream holes for field connections, as this facilitates erection, but not otherwise, unless in steel so hard that there is danger of cracking the material in punching. He is not so sure, however, that this is required, even for medium steel, and certainly not for soft steel. The fact that most manufacturers do not like to ream work, as acknowledged by the author, goes to show that they do not think it necessary, and that they can do good work without it, as they otherwise would certainly rather ream their work and get paid extra for it than punch it unevenly and have to drift excessively, which would cost them almost as much as reaming, and for which they would not be paid.

Another point the writer does not believe in is that "every column ought to be anchored so firmly to the pedestal that failure by overturning or rupture would not occur in the neighborhood of the foot, if the bent were tested to destruction." He does not believe in it because it is impossible to accomplish it without a great deal of extra expense, and in some cases it is impossible anyway. All columns should be well anchored, so well as to resist all shear coming against their bottoms and to resist tension if there is any. He thinks it preferable to treat the columns as free at the bottom and increase the section in figuring for bending effects of longitudinal and transverse thrusts than to treat it as fixed and attempt to build it as such. It is doubtful whether the cost would be any more that way, in most cases, than with the anchors proposed in the paper, and the column cannot really be made continuous except by running it down and embedding it in the concrete for a considerable distance, which would be very expensive and in many cases an impossibility. Again, there are cases where the columns have no bending to take care of, when it would manifestly be a waste of money to anchor them so as to make them continuous.

By Wm. Barclay Parsons, M. Am. Soc. C. E.

An elevated railroad, if built along a street, should be designed primarily from the point of view of the users of the street and not from the point of view of the railroad. A street is not a proper place for fast-running, power-driven railways. Such railways can be better built for their own uses on right of way to be acquired for the purpose, and when so built can be more satisfactorily operated. If for any reasons it is necessary to use a street, and the abutting owners and the users of the street surface are made to suffer *pro bono publico,* the greatest consideration in the design should be shown for their convenience.

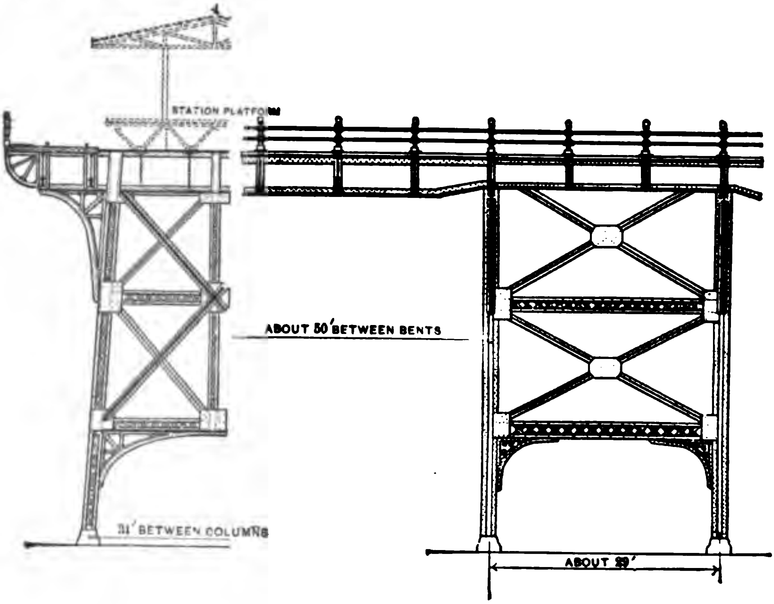

FIG. 33.

A design for an elevated railroad, apart from meeting the requirements of a bridge structure, as laid down by the author in his points F to O, under the head of designing, should conform to the following general requirements:

FIRST.—It should occupy as little of the street as possible.

SECOND.—Its columns should be placed so as not to interfere with vehicular traffic.

THIRD.—It should give the minimum obstruction to the passage of light.

FOURTH.—It should be noiseless, or as near as it can be, to the passage of trains.

FIFTH.—The tracks should be placed preferably over the center of the street and not over the sidewalks, so that the drip in wet weather will fall upon the tops of vehicles rather than upon pedestrians.

SIXTH.—The structure should be inoffensive to the eye.

Strict economy in the design should be the last point to be considered, and therefore the spacing of the girders, both longitudinally and laterally, should be made to conform to local requirements. In order not to interfere with steel travel, longitudinal and cross bracing between the columns, except at a clear height of 12 feet above the surface of the street, is not possible. The ordinary heights, such as are to be found in elevated railroads, preclude any such bracing, and, therefore, the only stiffening that can be given either longitudinally or laterally is by means of corner brackets. The author points out very carefully the necessity for both longitudinal and lateral stiffness, and states that all elevated railroads as at present designed are merely examples of what not to do. Had he gone into a criticism of these awful examples, he would probably have mentioned their lack of stiffness as one of their chief defects.

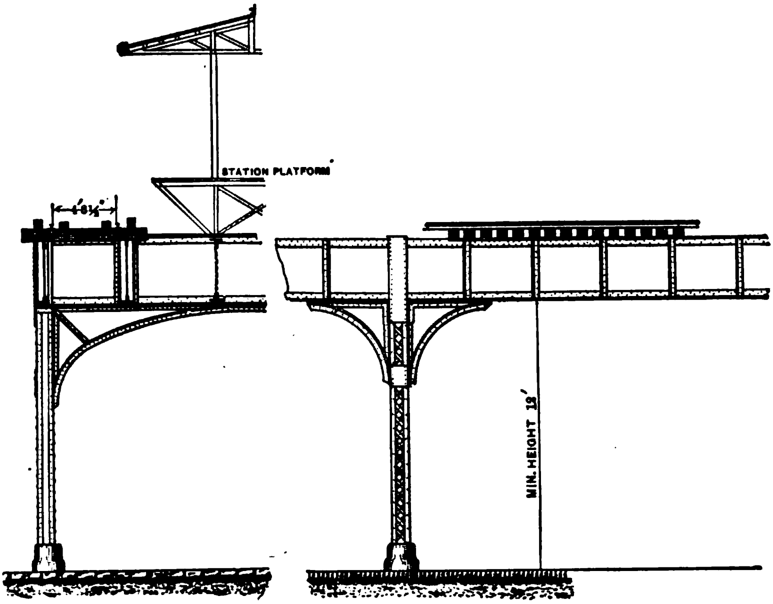

FIG. 34.

The writer some years ago had occasion to investigate personally the movement of New York elevated railroads under passing trains, which he did by means of a transit. He was surprised to find that on curves there was no movement perceptible beyond vibrations. This, however, was not the case with respect to longitudinal movement. At points near stations when the approaching trains applied brakes, the whole structure would move forward perceptibly. The instant that the brakes were released, although the train might still be in motion, the structure would go back beyond its original position and then move forward beyond the vertical hair of the transit, and back again before coming to rest.

Of the various designs submitted by the author for two-track structures, the writer prefers No. 8, where the outer stringers are in line with the columns. The objection urged by the author to this design in regard to the bending of the cross girders appears to the writer to be slight. Unless a column can be placed directly beneath the track, with stringers balanced about it, one stringer or the other will periodically be depressed slightly more than its mate. There is the advantage, however, of making at least one good connection, and of being able to introduce longitudinal brackets, which, like portal braces, can take up strain or movement.

The plans which the writer has prepared for the Rapid Transit Commission of New York include two designs for elevated railroads, one a high one across what is known as Manhattan Valley, 2,800 feet in length, and the other an ordinary structure. These designs are shown in Figs. 33 and 34. In the high one provision is to be made for four tracks eventually, but only the two outer ones to be constructed immediately. The intertrack space is to be utilized for island platforms. On account of the height, 55 feet, the structure in side elevation has been divided into alternating long and short spans with the towers rigidly braced. The design for the lower structure follows the general lines of the author's Design 8, lateral and longitudinal stiffness being supplied by the curved brackets.

The author speaks of making elevated railroads pleasing to the sight. That is an exceedingly difficult matter, if not impossible, unless the straight lines of utilitarianism aided by the details of good workmanship, can add beauty. Any built-up ornamentation, as in the aesthetic designs submitted by the author, will tend to still more darken and injure the street, and therefore by doing harm cannot be beautiful. It is to be remembered that true ornamentation should conform to, or suggest, the purpose of the whole, and the designs proposed by the author, while furnishing perhaps a pretty passageway to a ballroom, do not in their details, especially in the loose and festooned hand rail, seem to the writer as in keeping with a railway. The author has, however, done a good thing in calling attention to the needless ugliness of most of our structures. That possibly the simplest details are the best is exemplified in the Stadtbahn in Berlin, where the Germans, although lavishly ornate in most of the design, were much restrained in treating the metal elevated way. The columns are small, so as not to take up space, and of cast or wrought iron. In either case the decorations are in keeping with the metal. The supporting stringers are usually of plate-girder construction, and paneled between the stiffeners. The details of construction show care in execution and design. The side walls are bracketed out and so cast a deep shadow. The whole is pleasing to the eye.

By J. E. Greiner, M. Am. Soc. C. E.

The design of an engineering structure necessarily admits of a variety of means to accomplish the purpose intended, and the personal selection of any particular means does not imply that the preference is positively the best, or that a modification or different arrangement proposed by some other individual could not be equally as good. Therefore, while the author has pointed out what he considers the best cement, paint, span lengths, dimensions of track rails, arrangement of wooden floor, material for pedestal caps, style of anchors, sections for columns, style of expansion joints, etc., the selections made are to be understood as only the best which his judgment dictates, and not as yet definitely settled by either common concurrence or the ballot box. As this is a matter of individual judgment and opinion, a discussion would be useless; but the writer would really like to know why one coat of linseed oil, one coat of Eureka paint, and one coat of oxide paint, all on the same structure, are considered the best metal paints to adopt. There must be some reason for this variety.

The question raised concerning the use of the basic process for steel of a medium grade is an important one, as it is the tendency of the mills throughout the country, at the present time, to make just as little acid open-hearth steel as they possibly can. Basic open-hearth metal, when over 60,000 or 61,000 pounds ultimate, is not so uniform in quality and probably not so trustworthy as the acid steel, which must be made from a superior grade of ore, and the mills would always prefer to furnish the basic, which can be charged with cheap ores.

There is also a tendency at the present time among the different bridge shops, even those of the highest standing, to underrate the value of reaming and drilling a medium grade of steel. Of course all can understand that the object of the bridge shop is to manufacture a bridge just as cheaply as it can be done to the satisfaction of the buyer. If it can induce the buyer to avoid reaming or drilling, or planing sheared edges, it can complete its work at a somewhat less cost. It should not be censured when some of the most recent specifications allow this grade of steel to be used in the most important bridge structures at a higher unit stress than usual for soft steel, without requiring a better class of work. Personally the writer can see no reason why a higher unit stress should be allowed for medium steel than for a soft steel, if both grades are to be subjected to precisely the same treatment in the shops. If higher stresses be allowed for medium steel, then something more is required than merely an increased ultimate strength and an increased elastic limit, and any specifications which increase the unit stress for a medium steel, without at the same time providing for the necessary precautions to insure accurate workmanship and removal of incipient cracks, are taking a stand, which, while probably sanctioned by the manufacturers whose interest it is to cheapen work, should not meet with the approval of engineers who count on every square inch of section in their structures as available material undamaged by shop manipulation. Soft steel, that is, steel between 52,000 and 60,000 pounds, can be treated just the same as iron up to a certain thickness was treated. This is generally admitted. The metal flows easily, it is not liable to crack and will stand an immense amount of abuse, and if the shop punching is fairly well done and all important field connections matched in the shop and reamed, there is no doubt but that the result will be a first-class structure.

What argument can be advanced which will justify the use of a harder metal at a higher unit stress than allowed for soft steel when this harder material has nothing in its favor except a little higher ultimate and a little higher elastic limit? It is inferior in ductility, it is more apt to be brittle, it will not stand the same amount of drifting, bending or other abuse usually required for soft steel, and it is injured to a greater extent than soft steel by punching and other rough shopwork. When using a harder steel with a higher unit stress engineers should insist upon treatment and workmanship which will minimize abuse, and, as the author states, there is no bridge shop in existence which can turn out thoroughly first-class work without reaming or drilling.

The probability of increased train loads in the future, and an occasional blow from derailment, and the continual vibration due to fast speed, all have a tendency to develop flaws or defects invited by rough workmanship. This development may not take place to-day or to-morrow, but who can say that it will not occur the day after? Precautions taken in the interest of safety should not be sacrificed for the sake of a very small fraction of a cent per pound.

In this connection the writer desires to state that, while at the present time he is using both soft and medium steel, the former treated same as iron and worked with a low unit stress, the latter reamed or drilled and a higher unit stress used, he believes that should he have occasion to renew his 1896 specifications, he would specify but one grade of steel, having 60,000 pounds ultimate with a variation of 5,000 pounds more or less. He would use soft steel unit stresses for ordinary bridges, and work the steel without drilling or reaming except in important connections. For bridges having spans of 250 feet or more, he would use higher unit stresses, and ream or drill all holes, and would consider that the benefit derived from the more accurate workmanship would justify the increased unit stresses for precisely the same grade of material.

By W. E. Belknap, Assoc. M. Am. Soc. C. E.

Taking up Section 3 of the paper, which is headed "The Best and Cheapest Kind of Portland Cement to Adopt, and the Best Proportions for Concrete Made with Same," it will be found that in the specifications for the "best quality obtainable" of Portland cement, the requirements for neat tensile strength for twenty-eight days are 400 pounds per square inch. The specifications read, "from 400 to 600 pounds," but the minimum limitation alone carries weight. The writer ventures to assert that there are quite a number of high-class domestic Portlands that will run, not only about 400, but far above 600 pounds on a 28-day test, and that it would be the common opinion among engineers that such cements would be much better than a 400 pound cement. The same criticism is applicable to the requirements for sand briquettes. The writer has no intention of suggesting the requirements for "best" Portland cement, but is of the opinion that while the author's recommendations might secure the cheapest, they certainly do not assure the best.

The value of stating a requirement which ranges between limits from 50 to 150 per cent. of the minimum apart is difficult to discern. Specifications should as much as possible avoid compelling verbal explanation. If the engineer's minimum limit for a certain quality is fixed in his own mind, he should state it explicitly and adhere to it. A dealer supplying 600 pound cement does not ordinarily place himself in competition with a

400 pound article; and it is quite apparent that under the last clause of these specifications, to secure the chief engineer's approval of his own brand as a "best" cement with any meaning, he must also secure the disapproval of 400 pound brands. These are specifications which do not specify.

With respect to the author's suggestions concerning concrete for pedestals, the writer is of opinion that with either graded or uniform-size stone, the voids of the same can be filled with mortar in a one-three-six mixture, and that this is more dependent on the manipulation and subsequent consolidation of the concrete in place than on grading the stone very carefully and thoroughly mixing the various sizes, each of which precautions would probably cost considerable, were they literally carried out as the author suggests.

Mr. W. M. Patton, in his "Civil Engineering," gives the voids in concrete stone as follows:

Uniform size—2½-inch ring	37.07 per cent.
Uniform size—2-inch ring	39.50 per cent.
Uniform size—1½-inch ring	42.00 per cent.

Mr. A. W. Dow, in the "Report of Engineer Commissioner of District of Columbia, for 1896," gives the voids as follows:

Average concrete bluestone	45.3 per cent.
Coarse concrete stone	45.3 per cent.
Mixture of 1 part average concrete stone, 1 part small gravel	35.5 per cent.
Mixture of 2 parts average concrete stone, 1 part small gravel	36.7 per cent.
Mixture of 3 parts average concrete stone, 1 part granolithic bluestone	39.5 per cent.
Gravel, "average gravel"	29.3 per cent.

William M. Black, M. Am. Soc. C. E., in "United States Public Works," gives the voids in screened and washed, piled loose, concrete stone passing a 2 inch ring, as 46.5 per cent. The writer has found the voids in washed gravel of mixed sizes running from 2½ to ½ inch to be 41.0 per cent.

It will be noted that in none of these cases do the voids amount to 50 per cent. Theoretically, therefore, in a one-three-six mixture the mortar would be in excess of the amount required to fill the voids. In the relation of mortar to stone this mixture is almost practically the same as a one-two-four mixture, with which the writer has experienced no difficulty in the matter of filling the voids without taking either of the precautions referred to.

While it apparently stands so in the paper, the writer does not believe that the author recommends an "eminently slow-setting cement" for concrete to be deposited under water.

A combination of Sections 5 and 12 of the paper leads the reader to infer that the only timber used was "vulcanized" long-leaf yellow pine passing "clear" inspection. It is difficult to conceive that a railroad company would countenance the gross extravagance of using the most costly grade of timber when the preservative treatment of cheaper grades would give an article much more economical. The claims of economy set forth by the various preservative companies are based in a large part on the probability of making the inferior grades of timber more durable than the higher grades. In relation to "Vulcanizing," it may be pertinent to quote from a publication* of the Division of Forestry, Department of Agriculture. In this process it is claimed that "the chemical condition of the sap may be changed into a preservative composition" by heating the timbers to "from 300° to 500° Fahr. under air pressure of 100 to 175 pounds per square inch"; or "by substituting a vacuum for the pressure and a low temperature to effect the same result, namely, to 'vulcanize' the wood. There is no knowledge of the physiology or character of wood to sustain the claim of the physical change, nor has the material been long enough on trial to prove by experience the value of the process. Tests of treated and untreated material of such nature as to make the material comparable otherwise, made by the Forestry Division, did not show any increase in strength, as claimed, nor any chemical or physical changes."

In view of this statement of the Forestry Division, which must be given considerable authority in such matters, such data and tests as the author may have contradictory to the preceding would be not only interesting but very valuable, particularly as his figures demonstrate a large economy on the assumption of the process being efficient.

By W. L. Cowles, M. Am. Soc. C. E.

The paper is a valuable contribution to the literature on this subject, and is especially commendable in calling attention to the defects in existing structures, and in laying down the broad principle that an elevated railroad should be equal in all respects to the best class of railroad bridges. It would seem that this proposition should need no argument, for, as the author says, the service of the structure is much more constant than that of most railroad bridges, and the maximum load effect is more frequently reached, while the successive starting and stopping, with the attendant longitudinal thrust caused by the braking, calls for special rigidity in its design and the best of shopwork in its execution. Surely an accident which might occur through faulty design or construction would not be attended with less serious results than a similar accident to a railroad bridge, while the possibilities of disaster as affecting adjoining property and loss of life in streets, through a collapse of an elevated structure, furnish additional reason for thoroughness.

The selection of material made by the author was doubtless in accordance with the results of his careful investigation, and seems to have been determined upon as giving the most economical construction upon the basis of universal reaming. There is probably little question as to the benefit accruing from reaming all holes in medium steel for the purpose of insuring solid metal around the holes, but the writer is not yet prepared to accept the statement made by the author that all material should be so treated. The author is quite correct in holding that even in the best shops it is impracticable to punch holes to match perfectly, and there is certainly

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*"Bulletin No. 9, 1894," p. 243.

advantage in the riveting if the component parts of members are so assembled that all rivets will enter the holes freely, but this object can be attained by the use of the tapered flexible reamer to which he refers. This he admits, but contends that in such holes the rivets will not completely fill out, and will therefore not act effectively. The writer understands that reference is made to long members, such as chords and posts of a bridge or columns of a building, and, as applied to such members, which constitute a large proportion of the work of most shops, he does not accept the force of the argument. The effective action of rivets in the body of such members does not depend upon the complete filling of the holes so much as upon the formation of full heads, well closed down upon the surface of the steel, since the office of the rivet is not to transmit shear, but to holds the component parts of the members tightly together, so that the strength of the unsupported portions of any part may in no case be less than the strength of the member as a whole. The rivets in reinforce or pin plates, in brackets on columns, in the ends of the flanges of girders, and in all positions where the full efficiency of the rivets in shear is required, should completely fill the holes, but such rivets ordinarily occur only in comparatively small portions of a member, and the component parts can generally be so adjusted that these holes will come fair, leaving what mismatching there may be to come in a part of the member where the rivets are not in shear, and where the flexible reamer will accomplish all that is necessary.

The writer is in favor of reaming all holes for field connections, especially where the number of holes is large or the connection complicated, and does not intend to argue for poor workmanship or careless punching, but is of the opinion that while there may be a satisfaction in the consciousness that work is nicely done, the extra expense involved in the subpunching and reaming of all holes in soft steel and iron is not commercially justified by any benefit derived therefrom. He does not believe that metal work constructed of such material, carefully punched and assembled and well riveted, can properly be excluded from the term "first-class work."

By A. C. Cunningham, M. Am. Soc. C. E.

Within the recollection of most members, when an engineer desired to build a structure of steel, it was only necessary for him to specify "steel" of certain physical properties. That he would obtain the product of the Bessemer converter was assured, for there was, at first, no choice or alternative. Some of these first specifications are in use to-day with few or no changes of importance, though far better steel is furnished under them than they were originally intended to cover, owing to improvements in manufacture and increased knowledge.

Some of this early Bessemer steel high in phosphorus and sulphur, overdosed with manganese, and filled with oxide of iron, would to-day be branded as a villainous mess. Of the structures made of this steel, many have been taken down, some have fallen down, and the balance will come down in some way in the course of time.

Engineers who were using steel presently had their attention called to another process than the Bessemer by which a better and more desirable product could be made, and which, by the time it reached the structural engineer, had become generally known as open-hearth steel. Where the best results were of more importance than the actual cost, open-hearth steel was now specified, and those whom necessity still compelled to use Bessemer steel made their specifications to read Bessemer or open-hearth steel, with little or no hope of getting the latter.

The deadly enemies of iron and steel have always been and always will be phosphorus and sulphur. Owing to the much greater cost of manufacture of the early open-hearth steel over Bessemer steel, a much better melting stock, lower in phosphorus and sulphur, could be used for the former without much increasing its cost, and to this superior melting stock was largely due the superiority of the open-hearth steel.

The superiority of open-hearth steel to Bessemer being partly due to improved methods which largely increased its cost, and partly due to the use of a better stock which did not much increase its cost, manufacturers of open-hearth steel at once called attention to this superiority of composition in advocating their product. Recognizing both advantages, the engineer who could not avail himself of the first took advantage of the second and began to put limits on the dangerous elements in Bessemer steel, rightly inferring that what would improve the one kind would improve the other. These first chemical limits for structural steel were quite generally confined to phosphorus.

Having discovered that phosphorus and sulphur could be neither utilized nor neutralized to any extent in steel, the steelmaker next turned his attention to eliminating these troublesome elements, with the happy result of developing the basic process of steel making. The mechanical differences between the basic and the older processes are slight, the chemical differences are great. Being made in the same kinds of furnaces and converters as the older steels this new product needed only a qualification to have a name, and was quite naturally called basic Bessemer and basic open-hearth steel.

The acceptance of these terms made at once a family name of Bessemer and open-hearth, and the originals were christened acid Bessemer and acid open-hearth. Specifications reading Bessemer steel or open-hearth steel were no longer definite, since Bessemer and open-hearth steels could each be made by either the acid or basic process.

The original open-hearth steel, now called acid open-hearth, is made by a comparatively simple process. The hearth of the furnace is lined with silica, whence the name acid, and on this is placed the melting stock, consisting of pig iron, iron or steel scrap and iron ore. This charge is melted down, the silicon and manganese burn out first, and then the carbon to the point desired by the steel maker, when the furnace work is complete. If the phosphorus and sulphur burned out also, the basic process would never have been heard of, but unfortunately they do not. Whatever amount of phosphorus and sulphur was in the original charge remains in the steel. From this the reason for the well-known uniformity of acid open-hearth steel may be seen. The phosphorus and sulphur can be exactly estimated from the original charge. The steelmaker has only to give his attention to the reduction of the carbon to the desired point, and when he has made his manganese additions, the steel is finished. Unless chemical limitations are placed upon the dangerous elements, acid open-hearth steel may be uniformly bad, instead of uniformly good.

In the basic open-hearth process the hearth is lined with dolomite. In addition to the pig, scrap and ore, the charge contains lime. From the dolomite lining and the lime in the charge comes the name basic. The object of the lime in the charge is to unite with the phosphorus and sulphur, and pass them into the slag. Were lime charged into an acid furnace, it would act on the silica lining in preference to the phosphorus, but in the basic furnace it has no action on the dolomite. The greatest action of the lime in a basic charge is on the phosphorus; its action on the sulphur is much less.

The basic process being essentially a dephosphorizing one, it is possible to use for it a melting stock so high in phosphorus that steel made from the same stock by an acid process would be worthless. The regulation of the carbon becomes therefore of secondary importance to the reduction of the phosphorus to at least a safe limit, and as the carbon may be nearly all eliminated before the phosphorus is reduced, it becomes necessary in most cases to make carbon additions. It is not essential to the success of the process that the phosphorus in a basic open-hearth charge should be large; it may be as low or lower than in a charge for good acid steel, in which case the phosphorus will be nearly all eliminated.

The irregularities of basic open-hearth steel may be best illustrated by assuming a specification, and then seeing what may happen under it. As sometimes happens a specification originally intended for acid steel is applied to basic without change, and as this will give an extreme case, such a one will be taken; ultimate strength, 60,000 to 70,000 pounds per square inch, phosphorus not to exceed 0.08 per cent.

A cast containing 0.08 per cent. phosphorus would require 0.12 per cent. carbon to give 60,000 pounds in ordinary sections, and a cast containing only a trace of phosphorus would require 0.3 per cent. to give it 70,000 pounds under the same conditions. By skilful treatment both these casts may be made to pass the same specification, though they are at the extreme limits. Now, under varying conditions, these two casts will give very different results. The 0.3 per cent. carbon cast will be found much more sensitive to heat treatment than the other, and can be hardened to a much greater extent, and correspondingly softened on annealing.

Specifications for basic open-hearth steel seldom allow the phosphorus to exceed 0.04 per cent. or 0.05 per cent., but they never prevent it from going to a trace, which frequently happens, and if the allowed variation in ultimate is, say, 56,000 to 64,000 pounds, steel having from 0.12 per cent. to 0.24 per cent. carbon may be found under such a specification.

Such variations as this are not likely to be found in acid open-hearth steel, for, if the phosphorus limit is 0.08 per cent., the steelmaker will not go much below this on account of the increased cost of the raw material. With basic open-hearth, however, the difference in cost between 0.04 per cent. and a trace of phosphorus is only the difference of the slight excess of lime required to produce it.

Basic open-hearth steel is naturally a soft material on account of the low point to which the carbon is reduced in the furnace, and if a high ultimate is desired, it must be reached by adding carbon to the steel at the end of the process. Such carbon additions are made by throwing coke into the ladle into which the steel is tapped, and, as this does not always become thoroughly mixed with the steel, some parts are sometimes found to be harder than others.

From the foregoing it may be inferred that several heats of basic open-hearth steel may fill a specification, be of excellent quality, and at the same time of variable composition. Unless sulphur is limited in a specification for basic open-hearth steel, it is possible to get a product which is high in this dangerous element, for it is not reduced to the same extent by the process as the phosphorus.

There are advantages in connection with the basic open-hearth which are of great importance, and the principal ones are the possibility of producing a very low phosphorus steel and a very soft and ductile one at a moderate price.

The low phosphorus scrap resulting from the basic process, however, at once permits of a low phosphorus acid steel at a competing price, and when strong steels are wanted, they can be made with more regularity and certainty by the acid process than by the basic, for they do not depend on carbon additions to the same extent, and are, therefore, freer from the possibility of uneven mixing.

When it is desired to make a specification to cover both acid and basic open-hearth steel, it is well to make separate provisions for the chemical limitations at least. For acid steel a limit of 0.08 per cent. of phosphorus and 0.06 per cent. of sulphur, and for basic steel a limit of 0.04 per cent. of phosphorus and 0.05 per cent. of sulphur will produce good results and admit of competition between the two steels.

A range in ultimate strength between 56,000 and 64,000 pounds will cover both steels to advantage. For basic open-hearth alone, 52,000 to 60,000 pounds will give excellent results, while for acid open-hearth 60,000 to 68,000 pounds will be found quite uniform and reliable.

By C. E. Fowler, Assoc. M. Soc. C. E.

The attention paid to the details of the work, as evinced by the paper, is certainly commendable. Very few realize, however, as can the bridge companies which are doing work under many different engineers, what a great variety of details are considered best. One point that has impressed the writer on most recent work is the tendency to err on the safe side, if such can be called error.

After working under specifications of many of the trunk lines and of many consulting engineers, the writer has adopted in his own specifications soft medium steel, from 55,000 to 65,000 pounds ultimate, as being the metal that will undergo the manufacturing processes with least liability to damage, and avoid the necessity for reaming.

As most shops get out work at the present time, making a wood templet for each piece in a structure, it can only be extreme carelessness if holes in assembled members do not match well, and it is usual to see the holes match perfectly in girder flanges for the entire length. Compressed air reamers are used in most shops on all work to clean out the burrs and true up holes, thus avoiding the cause of drifting, and saving delay and expense in shopwork. It is not usual to use reamers of such great taper as the paper seems to suppose, and practically true holes result. For reamed work where $\frac{1}{16}$ inch is to be removed, twist drills are used, and with experienced workmen work is done which cannot be distinguished from that of fixed machines. The adaptability of such machines to varying conditions in shops is no doubt what commends them to shop owners.

As to acid and basic steel, the question is being settled by the mill owners, who are preparing to furnish the basic product as against the acid. At one of the largest mills in this country basic steel is being turned out in which it is unusual to find the phosphorus exceeding 0.01 per cent., and the greater part of the output contains only a trace. That this will more than offset any small gain in the uniformity of the product of acid furnaces, which is no doubt due to the better stock used, will certainly be admitted by most users of steel.

As great a problem is presented in what paint to use as in any point in the paper. During the past two years each engineer has had his favorite paint, one for painting work at the shop and still a different kind in the field. After seeing scores of brands used, the writer has come to doubt if any paint is wholly good or accomplishes its purpose. There is certainly a growing assurance among engineers that linseed oil is not the proper shop coat, and carbon primer is the favorite as a substitute. Experience shows the change to be a wise one, as it forms an elastic covering and is said to act chemically on the surface of the metal. What to do to remove the scale from steel before getting this first coat is a question. Will the mills devise some way to free their product from scale, or will the buyer pay to have the steel pickled? This is a much greater question than the field coat, as any of a dozen paints are first class for this, with the lead and graphite paints counted best. This coat should always be a different shade or color from the shop coat to make it easy to see when all parts are covered.

That the granitoid caps to exclude moisture from the pedestals are excellent is true, but it is a question if Portland concrete, properly crowned, would not have been sufficient.

The proportions for concrete are such as would give excellent results in practice, and if care is used these proportions would give satisfactory results under water. On some recent foundations, exactly these proportions were used by the writer and the concrete deposited under 15 feet of water; when the work was pumped out, the concrete was found to be very uniform and set firm and hard. The uniformity was accomplished by depositing it through a tube, the first filling of the tube being accomplished by sliding paper sacks filled with concrete into the tube until above water level. For such work as pedestals, proportions as high as one-four-seven for Portland will be found to give much better results, when the voids in the stone do not exceed four-tenths, than the more frequently used one-two-four natural cement concrete.

The limit for plate girders has been much extended, and it is customary for bridge shops to have orders booked for many spans at a time, from 70 to 125 feet in length, while a few years ago riveted lattice spans would have been used. The usual limit for plate girders does not, however, exceed 90 feet. The great difference in cost is in the cheaper erection of plate girders, as they can be placed in position as complete spans during the intervals between passing trains, as was done on the Cleveland, Akron and Columbus Railway during the past year, where each complete span weighed about 40 tons. The girders were so designed as to go between the trusses of the old Howe truss spans, after the old deck was torn away.

The limit usually adopted for crimping stiffeners is beyond 36 inches in depth, below which depth fillers are used. Some loss in stiffness is caused by the omission of the fillers, but the same weight of metal could more effectively be added to increase the size of the stiffeners.

Of the columns used, the two channels and one beam would find most favor in a shop, as the Z-bar column is difficult to keep from twisting during the punching and riveting. There is, however, a chance for some person to design a column which will meet the objections to which the different designs are subject, that is, a column where all the rivets are easy to drive, that does not twist so easily in making, and will have more satisfactory methods of detailing, as regards the development of the strength of the column as a whole.

The experiments as to the pressed threads are very interesting, and such threads should certainly be used for many cases where bolts are employed under heavy stress, such as anchor bolts and main connections where rivets cannot be put in.

It is to be hoped that the author will give fully the results of the experiments on angles connected by one leg and star struts, as these are in such general use that the information will be awaited with interest. They affect not only the class of structures under discussion, but more particularly the construction of mill buildings.

It cannot be too firmly impressed on the young members of the profession, that one or two rivets do not make a connection. Even if the rivets are driven tight at the time the work is done, one rivet in a two-rivet joint may work loose and then it is left for one rivet to ward off accident, when, perhaps, the structure has been subjected to heavier loads than those for which it was designed. The writer had supposed that spans of any size where the riveted members did not intersect on centers of gravity was a thing of the past, but a recently constructed riveted bridge of 100-foot span was seen in a Western city, with no attempt made to have the members intersect correctly. This lack of design has become so exceptional, however, that anything of the kind is very noticeable, and most of the bad features of the older elevated roads which are mentioned are, happily, things of the past. While there is much room yet for the improvement of steel structural designs, there is reason for congratulation that there is a constant demand for the best in both material and design.

By Samuel Tobias Wagner, M. Am. Soc. C. E.

The question of sub-punching in order to obtain the accurate matching of rivet holes by subsequent reaming is one that, without doubt, is conducive to the best results as far as perfect riveting is concerned, although it has been the experience of the writer that the engineer who assumes that by this means he will obtain good matching of holes together with the removal of the $\frac{1}{16}$ inch of injured metal around the holes will deceive him-

self. The same experience, however, leads him to believe that no serious injury to the metal will result, even if the higher limits of what is usually specified as medium steel are used. The inaccuracies in the holes alluded to are specially noticeable in the case of long plate girders where the web plates are rolled in long lengths and the chord angles have rivet holes in both legs, the stretching of the metal in the long chord angles producing the trouble.

The writer cannot too heartily agree with the statement that real reaming can only be done with rigid reamers, although in poorly matched holes the removal of the injured metal in the holes will not be entirely accomplished, as would be the case if the reamer were allowed to follow the hole. He has more confidence, however, in the rivet practically filling an irregular hole when the rivet is driven by hydraulic power than the author of the paper has. Sub-punching and reaming must of necessity cost more than ordinary punching on account of the extra handling required and the delay in the transit of the material through the shops, and it is therefore simply a question for the engineer to decide as to whether the improved quality of the work is justified by the additional cost incurred. It is the opinion of the writer that for shop driven rivets, and with soft steel of from, say, 57,000 to 65,000 pounds ultimate strength, an ordinary fair increase in the cost per pound is not warranted. On the other hand holes for field-driven rivets cannot match too well, and even a decidedly increased cost would be warranted in obtaining them. This is, of course, due to the difficulty of obtaining a good rivet in the field when driven by hand.

Railroad bridge work has, on account of the special care which has been given in the past to its designing, represented the best practice in structural work, but the writer agrees with the author that there is no reason why it should stand alone in this respect, and endorses the stand he has taken regarding elevated railroad work. He would even go further, and can see no reason why any structure carefully and economically designed should not receive equally as much care in the requirements of its manufacture. It is to be assumed that when an engineer prepares a specification for any work, he does it in the interest of those paying for the work, and that it has received careful consideration, and should therefore stand after the contract is made. The practice of the contractor speculating upon future changes is much to be deplored, and is a condition of things which should never exist. No changes in the requirements should ever be allowed after the contract is signed unless the very strongest reasons exist for so doing. No alternate bid should in equity be considered unless it is asked for in the proposal.

The use of basic steel is a very pertinent one at the present time, and it would be interesting if the author would give his reasons for limiting the use of this metal. The writer is of the opinion that for most purposes (eyebars possibly excepted) the basic metal is equal to that produced in an acid furnace.

As to the remarks on cements and concrete, the results arrived at are those specified for the construction of the work on the subway and tunnel on Pennsylvania Avenue in Philadelphia, for abolishing all grade crossings on that avenue, a work costing $6,000,000. The specifications for the Portland cement (which is specified for all stone masonry and concrete) follow, and compliance with the specifications has so far been obtained without

difficulty, and in some cases very much exceeded. Attention is specially called to the mortar-box tests, which are regularly taken and have proved of great value on this work.

"The acceptance of a cement to be used in the work shall rest with the Chief Engineer, and will be based on the following requirements:

"Portland Cement.—Portland cement shall have a specific gravity of not less than 3, and shall leave by weight a residue of not more than 1 per cent. on a No. 50 sieve, 10 per cent. on a No. 100 sieve, and 30 per cent. on a No. 200 sieve, the sieves being the same as previously described.

"Pats of neat cement ½ inch thick, with thin edges, immersed in water, after 'hard' set, shall show no signs of 'checking' or disintegration.

"It shall require at least 30 minutes to develop initial 'set,' under the same conditions as specified for Natural Cement.

"Briquettes of neat cement, 1 square inch in section, shall develop the following ultimate tensile strengths:

Age.	Strength.
24 hours (in water after 'hard' set)	175 lbs.
7 days (1 day in air, 6 days in water)	450 "
28 " (1 " " 27 " ")	550 "
7 " (1 " " 6 " "), 1 part of cement to 3 parts of standard quartz sand	160 "
28 " (1 day in air, 27 days in water), 1 part of cement to 3 parts of standard quartz sand	220 "

"All cements shall meet such additional requirements as to 'hot water,' 'set,' and 'chemical' tests as the Chief Engineer may determine. The requirements for 'set' may be modified where the conditions are such as to make it advisable.

"Mortar taken from the mixing box, and molded into briquettes 1 square inch in cross-section, shall develop the following ultimate tensile strength:

Age.	Strength.
7 days (1 day in air, 6 days in water), 1 part Portland cement to 3 parts of sand	100 lbs.
28 " (1 day in air, 27 days in water) 1 part of Portland cement to 3 parts of sand	150 " "

A comparison of the specifications shows a fairly close agreement in the requirements, the specifications just given being slightly harder to fill.

The specifications for the concrete on this work require the same proportions as given by the author, viz., one part of cement, two parts of sand, and five parts of broken stone, which is not required to be graded.

The question of painting is one deserving of the greatest care, and the results of any experiments must of necessity be interesting. Without entering into detail the writer from his experience warmly recommends the practice of giving the metal a coat of linseed oil before leaving the cover of the mill and after all loose black scale is removed. He believes this to be one of the secrets of the prevention of a large amount of rusting, no matter what priming and finishing coats are applied. These latter coats must of necessity vary somewhat with the locality and use of the structure, while this first precaution he believes to be essential in any structural work.

By Chas. F. Stowell, M. Am. Soc. C. E.

The safety and longevity of any iron or steel bridge is inversely proportional to the amount and extent of motion in the structure. Motion, as regards structures, may be divided into two kinds; dynamic, or that motion due to and inseparable from the imposition of stress, and physical, or motion of translation, which may or may not be accompanied by internal stress. Except when a bridge is moved bodily off its foundations, no failure ever has or ever can take place except as the immediate result of excessive dynamic motion. As long as a bridge contains metal in sufficient quantity and so disposed as to restrict the dynamic motion within certain limits, its life, so far as is known, will be perpetual; but as soon as the limit is exceeded in any one member, the failure of that member sooner or later is absolutely certain. In former times it was the rule, and even yet the practice obtains to some extent, to proportion bridges for stress alone without regard to motion; and many old bridges were simply statical stress sheets transformed into iron. If in any such bridges the dynamic motion was kept within safe limits it was a happy incident or accident of their construction. It is known now that a stress and section sheet is not a safe criterion of the value of a bridge, and that to insure permanence, not only the stress, but also the motion, must be considered and provided for.

When the earlier elevated structures were built, neither the loads to which they would be subjected were anticipated, nor was the subject of dynamic motion understood, and consequently these structures were soon found to lack both strength and rigidity. Remedies of various kinds have been applied to them from time to time to correct the former defect, but the latter is still obtrusively apparent to any observer. It can hardly be questioned that the life of the Manhattan elevated structure must be a limited one for this reason. Whether the limit is close at hand or still far off can only be judged by those in charge of and constantly observing the structure under its daily task. That such a limit was long ago recognized by its owners appears to be shown by these words of one of its officers published fourteen years ago: "The structure is an iron bridge for the whole length of the railway, miles in length; whether this will have to be rebuilt in ten years or fifty nobody yet knows."* The Chicago elevated structure offers a marked contrast to these older works in that not only strength but rigidity also is considered, and it is the first elevated structure within the writer's knowledge where the latter point has received any particular attention. He does not agree with the author as to the value of sub-punching and reaming. If such treatment is prescribed to cure the bad effect of punching, it is delusive. Solid drilling is the only safe course under those premises. The writer has yet to see any piece of work in which all the punched surface was removed from every hole, and unless it is so removed it is obviously useless to remove it from some and leave it on others. Instead of using material which is liable to injury in punching and then applying a remedy for the harm knowingly inflicted, it seems safer, and it is certainly cheaper, to get in the first place steel which will not be injuriously affected by punching and shearing. Such steel is not hard to get. A photograph, Plate X.,

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*Report of State Engineer and Comptroller in answer to resolution of New York State Senate, March 20th, 1883.

Fig. 1, is submitted of some tests on steel of this kind recently used in bridge work, which has stood much more abuse than it could ever possibly get in any shop, and still without reaching its limit of endurance. These test pieces were not specially selected, but were ordinary pieces picked up at random, and the tests were not nursed in the making to produce a fine show, as is sometimes the case, but were actually made in the roughest and hardest manner. This steel was 55,000 to 65,000 pounds ultimate, averaging about 62,000 pounds. After knowing the quality of this steel from the stock used in making it, from the process of manufacture and from its chemical analysis, and having demonstrated its properties by physical tests, the writer feels perfectly safe in using the material without sub-punching and reaming, and without planing sheared edges; far safer in fact than he would in using an inferior metal and doctoring it afterwards. This particular steel happens to be acid open-hearth, but he has no doubt that basic steel of corresponding good quality would show up equally well. This steel costs from 0.05 to 0.1 cent per pound more than ordinary steel, while the author's figures for the extra cost of sub-punching and reaming are from 0.1 to 0.2 cent per pound.

Reaming for fair holes and not primarily to remove the surface cut by the punch is quite another matter, but with care there need be very little, if any, such reaming done. The author is certainly wrong in saying that no shop can turn out first-class work without sub-punching and reaming or drilling. The writer has been accustomed to specify that when the rivet holes match sufficiently to let a cold rivet through, but not a hot one, they may be drifted fair, but any greater degree of mismatching must be corrected by reaming. In a shop where some care is taken with the punching, the amount of reaming under this specification is exceedingly small. The habitual use of the reamer to get fair holes prevails generally where the punching is piece-work. When a man's pay depends upon the number of holes he makes in a day, he is not likely to be over-careful where he puts them, especially if he knows some one will follow after him with a reamer to correct his inaccuracies. All this is unnecessary with a little care at the punch. Moreover, the writer is of the opinion that the rivets themselves hold better and are stronger in punched than in drilled or reamed holes.

Another consideration in regard to reaming to remove injured metal is this. Such holes are always punched in the first place, and often carelessly, as the man at the punch knows they are to be reamed afterwards. Before reaming, the work has to be fitted up and bolted through these punched holes, a process accompanied by more or less heavy drifting according to the degree of inaccuracy in the punching. If the original punching has started a crack in any hole, it will surely be extended by any drifting done on that hole. Can one always be absolutely certain that, whatever the amount of metal reamed out, it is enough to extend beyond the limit of any such crack? The writer thinks not.

One should, of course, use all reasonable precautions to get good and accurate work which will not require abuse of the metal in order to get the parts to go together. If in addition one is sure of having metal which can safely stand far more abuse than can ever possibly be put upon it, should it happen to get any, and which need not be gone over minutely to be sure that every bit of sheared surface has been removed, it is greatly conducive to a good night's sleep.

PLATE X.
TRANS. AM. SOC. CIV. ENGRS.
VOL. XXXVII, No. 806.
STOWELL ON ELEVATED RAILROADS.

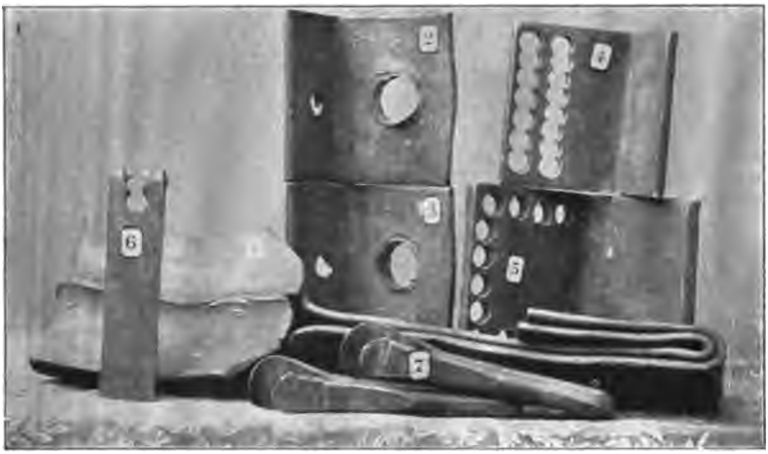

FIG. 1.

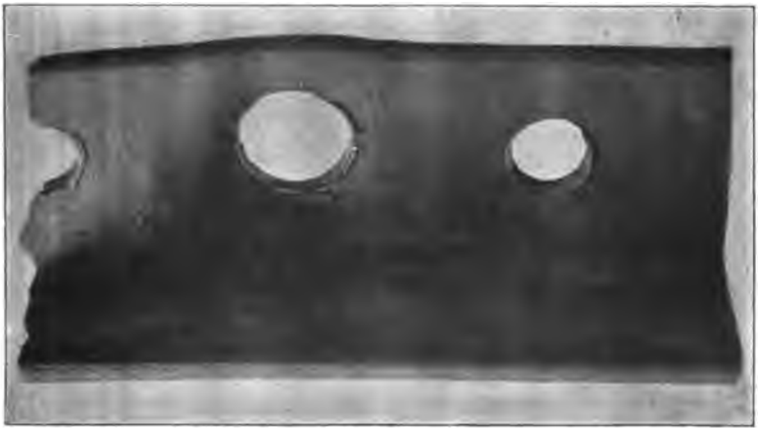

FIG. 2.

The steel specification for the Chicago elevated work called for open-hearth metal having an ultimate strength of 60,000 to 68,000 pounds per square inch; elastic limit, one-half of ultimate strength; percentage of elongation, ultimate divided by 1,500,000 (corresponding to about 25 per cent.); percentage of reduction, twice that of elongation; quench bend, 180 degrees around a diameter equal to the thickness of the test piece, and drift test to show an increase of 50 per cent. over original diameter of punched hole. The chemistry was prescribed only for phosphorus, which was not to exceed 0.08 per cent. for acid, and 0.05 per cent. for basic steel. This is a very good specification as far as it goes, and far superior to many in use. But the writer believes that not only the phosphorus, but also the sulphur should be limited. He is aware the manufacturer will claim that, inasmuch as sulphur is a red shortener, it may safely be left alone, as any excess will show itself in the breaking up of the steel in rolling. But this is not all. Experience has demonstrated that sulphur may exist so near the limit of red shortness that, while it does not cause the steel actually to disintegrate in rolling, it may leave the rolls full of minute fractures (micro-sulphur flaws) which cannot be detected by the eye, but which are liable to extend under stress and ultimately cause the fracture of the piece. For this reason the sulphur content should be kept well within the danger limit.

The author's requirement of a drift test showing 50 per cent. increase in diameter of punched holes is a good and reasonable one, but too much stress should not be placed on the drift test as indicating the quality of steel. If it does not stand a moderate amount of drifting, the steel is certainly poor, but if it does stand it, it by no means follows that it is good or even passable. The evidence of the drift pin should be considered as corroborative only, not absolute, as is the tendency in some quarters. There is a bridge specification very widely used and extensively copied throughout this country† which provides a drift test showing an increase of only one-third in the diameter of punched holes, and making such a test the criterion for reaming and planing or their omission. To show how utterly worthless such a test is, the writer submits an illustration (Plate X., Fig. 2) of a piece of angle iron with a punched hole drifted from $\frac{13}{16}$ to $1\frac{9}{32}$ inches diameter, or about 58 per cent. increase, and still without reaching the possible limit of drifting. In other words, this piece has filled the requirements of the specification and about 25 per cent. more, and under its requirements might be used without reaming or planing for any kind of bridge work under any circumstances. Yet the steel is so poor that the piece shown in the photograph broke off while trying to bend the angle iron to a curve of 40 feet radius. The peculiar feature of that specification is not only that it lays such stress on this worthless drift test, but, even should the steel be so unspeakably bad that it cannot stand this drifting, still it may be used provided only the holes are reamed and the edges planed.

The chemistry of this piece of steel is as follows: Carbon, 0.130 per cent.; phosphorus, 0.101 per cent.; sulphur, 0.056 per cent.; silicon, 0.040 per cent.; manganese, 0.591 per cent.

The analysis stamps the steel as a quite ordinary grade of (probably) Bessemer metal, and on the analysis alone it would be rejected for use in any important place; but the specification mentioned would permit its use for any purpose, as that specification ignores both chemistry and process of manufacture. The writer believes more poor steel has probably been put into American bridges under that specification than under any other ever written, and the reason why it does not more often show itself in failures is because manufacturers generally make a much better quality of steel than that specification would permit the use of. There is, fortunately, a limit to poverty in steel beyond which it does not pay to try to make it. When more than a certain percentage cannot be run through the rolls whole, the cost of such of the product as can be finished more than offsets the saving in the use of cheap stock. The tendency in steel making, too, is in the direction of continued improvement in its quality, and most manufacturers nowadays habitually turn out a pretty fair grade of metal, so that the purchaser under such a specification as is mentioned generally gets now a much better article than he calls for.

The author's experiments on the relative value of angle irons connected by one and by both legs are in accord with facts long known to those familiar with riveted construction. A good many modern specifications stipulate that angles must always be fastened by both legs or the section of one leg only be considered as available for stress. If it were true, or even approximately so, that the strength of an angle iron fastened by one leg is that of this leg only, a great many old riveted bridges would have broken down long ago, but they persistently refuse to collapse and verify the theory.

The author's design for an elevated structure is, on the whole, a distinct advance over all previous efforts in that line, and the care and study expended on the subject have resulted in a structure which apparently leaves little further improvement possible. The use of solid web girders instead of open web, the large and substantial knee braces at tops of columns, the scientific arrangement of the lateral bracing and the proportioning of columns and anchorages to withstand all possible horizontal as well as vertical loads, are particularly good features; and the writer ventures the prediction that future elevated roads will be largely modeled after this one.

The proposed design for an ornamental structure for city streets is a generally beautiful and tasteful design, unfortunately not likely to be realized in practice soon. There is one feature about it which the writer does not admire, namely, the making of the outlet for drain pipes through animals' mouths. The representation of a beast's head in the act of vomiting is not a pleasing spectacle.

By E. H. Connor, Assoc. M. Am. Soc. C. E.

The stresses used in the various members under varying conditions, and the unit prices assumed in the comparative designs, and their costs, are all omitted in the paper. The several points mentioned from A to P should, without doubt, receive due consideration, but the author does not state when he deems the columns "properly designed to provide sufficient strength," etc. The same may be said of many of the other articles. As all elevated railroads in Chicago are having a hard time financially, economy must be a very important factor in a design for that city. Certainly safety must not be sacrificed at any cost, but too much money should not be spent to overcome non-injurious vibrations. Vibrations are inherent in all metallic structures, and should simply be kept within proper limits.

The longitudinal girders used on the Northwestern Elevated road have been carefully designed and are well braced. Lattice girders are more pleasing in appearance, and admit more light to the street beneath. They are not so satisfactory for rigidity and maintenance as plate girders. The cost for 50-foot spans is about the same. The columns used on the same road were very difficult and expensive to manufacture on account of the large plate, over 6 feet square, with sectors cut out of the lower corners, on account of the connection taking the longitudinal thrust, with its irregularly cut plates, and on account of the many parts, over seventy in each column, which required the columns to be handled several times in assembling and riveting.

It is proper to allow high unit strains in the metal when the live load, dead load and bending moment are all considered; 15,000 pounds per square inch would not be too much for medium steel columns on a tangent. The longitudinal thrust due to an application of brakes on the entire train is distributed by the rails, floor and girders over a considerable length of the structure. If it is considered distributed over a distance equal to twice the length of the train, and carried by the columns within that distance, the longitudinal vibrations would be confined to small limits.

Columns of more pleasing appearance and sufficient rigidity can be built more economically of 15-inch channels, flared at the end to receive the stringers directly without cross girders, than those adopted by the author. The channels may be strengthened near the base by angles when it becomes necessary in long columns.

The maximum fiber stress due to the Northwestern loading, longitudinal and transverse bending, assuming the longitudinal thrust to be two tenths of the entire weight of a train 200 feet long, and distributed over 320 feet, or 8 bents, in a column 16 feet high built of two 15-inch, 33-pound channels would be about 12,500 pounds per square inch, a perfectly safe stress. The sectional area of this column is less than that of the one used, and no longitudinal tower bracing is required. The saving in columns and cross-girders would be considerable. Such columns have been in use in New York for many years, and are to-day satisfactorily performing their duties, though the vibrations are excessive, some of the details poor and the amount of care given them very small.

The rigidity could be increased by altering and strengthening the details. Longitudinal brackets riveted to the columns and bearing against stiff cross frames between the stringers could be introduced. The writer sees no reason, however, for discarding entirely the main features which are economical in material and shop labor.

The writer is glad to see the firm stand taken by the author in regard to punching and reaming rivet holes, and is sorry to note that facing the end angles of the longitudinal girders, almost equally desirable, was not required. The additional cost is very small. Such workmanship decreases the factor of ignorance as to existing conditions and permits the use of higher unit stresses.

By Henry W. Hodge, M. Am. Soc. C. E.

The paper will undoubtedly be of great advantage in improving the general designs and details of elevated railroad structures, though it is to be hoped that American cities are not to be afflicted with any large amount of such work. Aesthetics in an elevated railroad is, in the writer's opinion, purely a matter of imagination, and such structures cannot but be unsightly and ruinous to the appearance and comfort of any city street.

The writer cannot agree that it is advisable to reduce the ultimate stress on basic steel to 61,000 pounds, nor has it been his experience that basic steel is less uniform in quality than acid. The material for the Duluth and Superior Bridge was ordered under the following specifications: Ultimate, 63,000 to 70,000 pounds; elastic, 55 per cent. of ultimate; elongation in 8 inches, 22 per cent.; reduction, 40 per cent.

The use of either acid or basic steel was allowed, except that acid was required for eyebars. The acid was not to contain more than 0.08 per cent. of phosphorus, or the basic more than 0.04 per cent. of phosphorus. No difficulty was experienced in getting material of these qualifications, nor did the manufacturers object to it as difficult to make, and the amount of material rejected for failing to come up to these specifications was so small as to be hardly worth consideration. There were about 1,000 tons of acid steel and 2,000 tons of basic steel, and the maximum and minimum values obtained from all specimen tests, including the tests on material rejected, were as follows:

	Acid Steel.	Basic Steel.
Ultimate	58,710 to 74,840	51,780 to 76,700
Elastic	31,500 to 46,660	32,600 to 49,100
Elongation in 8 ins..	14.5 p.c. to 34.5 p.c.	17.5 p.c. to 33 p.c.
Reduction	25.6 p.c. to 63.7 p.c.	31.7 p.c. to 65.3 p.c.
Phosphorus	0.018 p.c. to 0.08 p.c.	0.007 p.c. to 0.036 p.c.

Considering there was twice as much basic as acid material, the writer thinks these results show basic steel to be not less uniform than acid. Of course, these values are all extremes from a very large number of tests, and in some cases are caused by hard or soft spots; so while they may not show the average character of the material, they at least show what extreme variations may be found in a large amount of material.

In this structure the metal for the wheel treads of the turntable was required to fill the following specification: Ultimate, 70,000 to 80,000 pounds; elastic, 50 per cent. of ultimate; elongation in 8 inches, 20 per cent.; reduction, 35 per cent.

The results of tests on basic steel were: Ultimate, 70,980 to 72,050 pounds; elastic, 47,240 to 49,150 pounds; elongation in 8 inches, 24.5 per cent. to 27.5 per cent.; reduction, 50.9 per cent. to 55.2 per cent.

As such a grade of basic steel can be made without greatly increased cost, the writer sees no reason for puting the ultimate so low as 61,000, and would advocate from 63,000 to 70,000 pounds. In the enumeration in the paper of faulty details, it seems to the writer that a number are not details at all, but main principles, as the designer who does not use sufficient bracing between longitudinal girders, or put sufficient rivets in joints, or proportion the chords of girders for bending as well as direct stress, or proportion columns for the horizontal as well as vertical loads, or use bases large enough to carry the loads under columns, is not worthy of the name of engineer. These and several other so-called details are such elementary matters, now so generally attended to, that it is certainly useless to call any reputable engineer's attention to them.

The writer thinks it unnecessary to increase the theoretical number of rivets in a member, if such number is small, for fear one may be loose, as such a possibility should be guarded against by setting proper valuations on rivet-bearing and shearing. If one started to "guess" how many extra rivets should be allowed at each joint, why trust to figures at all? Gravity lines should intersect in a point, of course, to prevent torsion on the riveted joints.

Nor does the writer see any reason why lacing should not be relied on to carry horizontal thrust in the column, as the lacing is generally on each side of the column, and in most cases has two rivets in each lattice, so it will be necessary for four rivets to be loose instead of one, as stated in the paper, to destroy the efficiency of the lattice. The necessity of giving away material to avoid any such improbable contingency is difficult to see. As to aesthetics, the writer believes that most engineers had by all means better call in an experienced architect to give assistance in such matters, as he thinks such a man's idea would doubtless be a great improvement on the one suggested.

By Bernt Berger, Assoc. M. Am. Soc. C. E.

The author states that the results of his examination of previously constructed elevated railroads amount simply to the accumulation of a great mass of information exemplifying "how not to do it." It appears, however, as if he has consciously or unconsciously made use of several features of the older systems of elevated railroads.

In all the early elevated railroad structures in New York the columns were anchored to the foundations, and the anchor rods were run through to the bottom and not stopped off in the middle of the mass. The writer does not mean to say that such anchorage is necessarily a point of excellence, but the idea is an old one. The rigid connection of the cross girders to the posts was used as early as 1878 in the City Hall branch of the elevated railroad in New York. Here the columns are formed of two 15-inch channels latticed and inserted into deep pedestal castings, which are anchored to the foundations. One channel is cut off under the bottom flange of the cross girder, which rests on it, and the other channel extends to the top flange of the girder and is riveted to its vertical end angles. Theodore Cooper, M. Am. Soc. C. E., who had charge of this work during its construction, copied this detail in his design of the elevated structure for the Pittsburg Junction Railroad in 1883, and the same method of connecting the cross-girders to the columns has been used in several other elevated railroad structures.

In Fig. 35 is shown a rigid connection of cross-girders to columns, where the former overhang the latter, employed by Mr. Cooper in his design for the Suburban Rapid Transit Railway in New York in 1886. The channels of the columns are cut off under the bottom flange of the cross girders, a batten plate extended up on each side of the girder to which are riveted two angles which again are riveted to web-stiffening angles on the girder. This top connection gives all the required rigidity to the structure. The foot of the columns is not anchored to the foundation, but rests on a cast-iron pedestal which raises it above the dirt and moisture of the street. The same cut also shows the expansion pocket. The pocket is particularly strong in the girder seat, the vertical webs of the channels precluding any possibility of undue yielding of the seat and working of the rivets.

Fig. 36 shows the expansion pocket for the railroad stringers of the Asylum Street improvements at Hartford, Conn. This elevated railroad structure was built in 1888, is about 670 feet long, in part on a curve, and carries four tracks and three platforms. It was designed for Class A of Mr. Cooper's specifications. The pocket is a very strong and rigid one, the side plates and angles having been extended the full depth of the cross girder. In the same structure stiff transverse sway bracing was used.

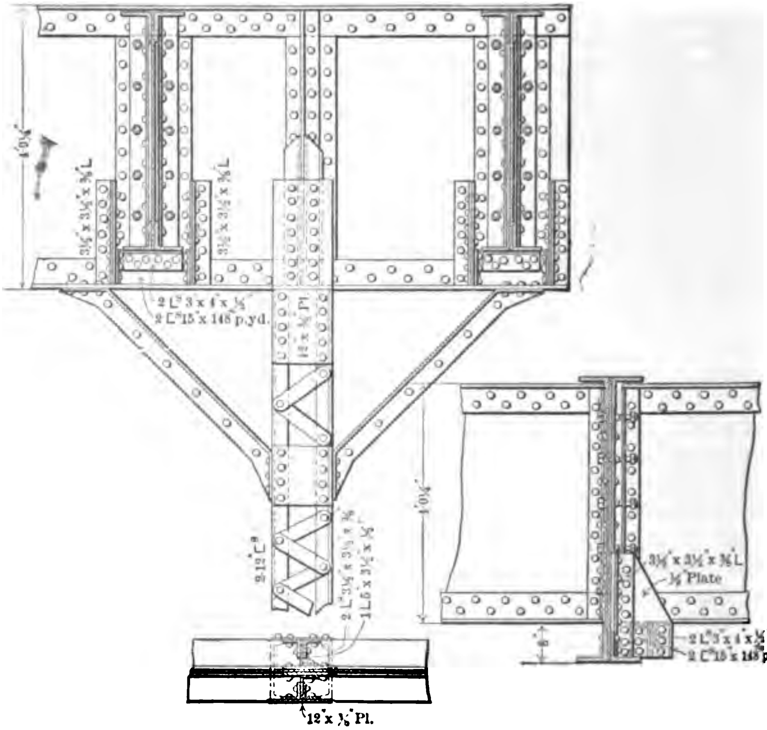

FIG. 35.

Both expansion pockets are provided with ⅞-inch safety bolts to prevent any possibility of the contraction of the structure under falling temperature becoming concentrated at any one pocket.

The introduction of braced towers is admirable, and it is the author's good fortune that his structure was so located as to permit it. The writer is in accord with him in his strong plea for reaming of riveted members, which reaming must, however, by no means be understood to do away with careful work in punching.

By Walter T. Smith, Jun. Am. Soc. C. E.

The writer, who was connected for over two and one-half years with the Wabash Avenue extension of the Lake Street road and with both the Northwestern and Union Elevated construction, touches on the following features, not in a spirit of criticism, but rather that some views contrary to those of the author may be noted and corrected if wrong.

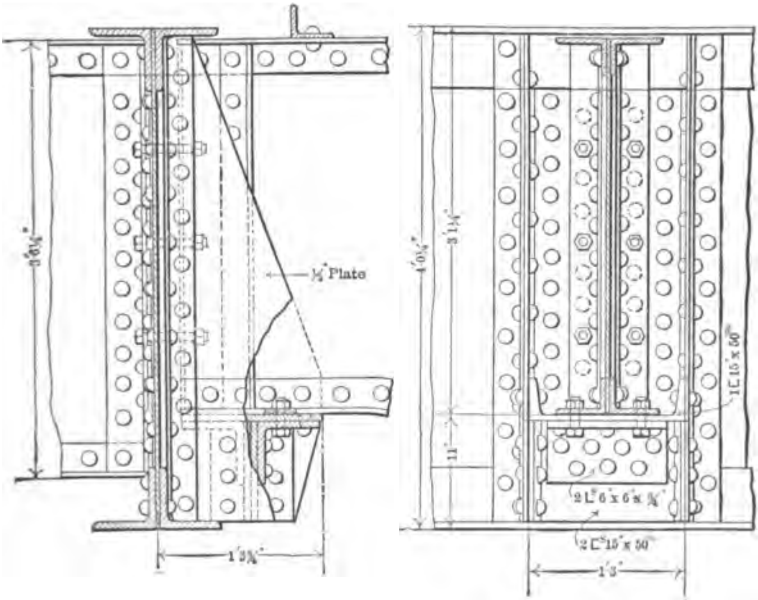

FIG. 36.

The first subject is the radical change over other elevated road construction in the introduction of tower spans, 23 feet 6 inches center to center of columns, braced both longitudinally and transversely to the column foot, as shown in the details. The reason given for this is the fact that express trains are to be run over the surface at a rate of 40 miles per hour, making this condition necessary to take the traction force due to the braked train. This assumption was made, evidently, owing to the fact that every fourth span has an expansion joint, thereby making it impossible to direct this longitudinal force into more than four spans or sixteen columns at one time, or at least during the period of maximum stress. This would be true without doubt were the structure proper only to be taken into consideration, but this view does not show all the facts of the case.

The maximum condition of stress is due to a loaded train consisting of one motor car and three trailers, weighing in all about 180,000 pounds, running at the rate of 40 miles per hour. It is found necessary to stop this train in the least possible time. By knowing the distance which the train travels after brakes are applied and the time necessary to bring it to a stop, the calculation of the force of traction or thrust could be made without difficulty. This whole force would be applied to a single section between two expansion joints, owing to the fact that the train length is about 150 feet, while the distance between the expansion joints is, at times, more, were it not for the deck work, and this changes existing conditions totally. In each track system there are four guard rails and two running rails. These six rails form the structure into a mass in such a manner that if a strain is put upon any part of the deck, it is carried over a large extent of its surface. It is true that the space for expansion of the running rail would tend to cause a sliding of that rail were any considerable longitudinal strain put upon it.

In case this sliding does occur, the friction of the spike and tie bearing will convey the thrust into the tie, and from there it must either be taken up by the tie bearing of the girder or by the guard rail. Reason would certainly denote the latter, for the ties and guard rails are bolted together in such a manner as to render it impossible for one to act without the other, while the connection between the tie and the girder is not by any means a complete one, for if such were the case, expansion of the metal would injure the alignment of the deck. This last statement is true to a greater extent of the roads in question than on the Metropolitan Elevated of Chicago, for that road has bolted all ties to the flange of the girder while the Northwestern and Union Elevated use hook bolts on each second tie only.

The conclusion drawn from these conditions is that the stress due to braked trains is not conveyed, to any extent, to the columns. It would be unreasonable to say that this stress does not affect the columns at all, for the fact that the longitudinals and columns are riveted together makes it impossible for one to act without some effect on the other. At the same time no bending can be produced upon the column, for it is counteracted by the deck. Were the longitudinals made continuous for long distances and the only connections with the columns were by bearing plates or rolls, so as to leave absolutely no resistance but that of a body at rest, there would be no direct longitudinal motion. This would have a tendency to aggravate the transverse stress greatly, in that it would be continuous, and for that reason, if no other, the author's idea of carrying the columns to the full height of the structure is to be commended.

A point of contention might be as to whether the mass of the structure is in stable or unstable equilibrium. The fact that a large body is supported by a column of small area in proportion to its size, or a number of them, does not make it unstable, provided the forces acting upon that body do not tend to move it to a sufficient extent that its own weight is added to the forces already employed. Were the action of the train large enough in proportion to the structure affected to produce a tendency in the mass of the steel to move in the direction that the train travels and thereby lend its own weight to the force of the train, the bending of the columns would be severe. This is not, however, within the bounds of reason and can be at once dismissed. It will be assumed that the action of this longitudinal thrust is wholly taken up by that portion of the structure upon which the train runs, that is, upon two of the longitudinals with the deck. This assumption is greatly on the side of safety, for the design of the structure makes it impossible to strain this one-track system without affecting to some degree the other three, and especially that on the same side of the center. If the force is confined to this single track, however, and its action does not extend more than twice or three times the length of the train in either direction, there is a weight equal to three times that of the train which must needs be set in motion before bending can occur. Were it possible to design a column section in any case, which would carry the load due to compression, without longitudinal strength, then some metal might, in this case, be necessary to withstand any light stress caused by thrust. This being impossible, however, the conclusion is drawn that any metal used in any part of the structure to withstand horizontal thrust in a longitudinal direction is superfluous and a needless expense. This same rule could be applied to the transverse bracing of the towers in a four-track structure. The force of impact is not severe, and the width of the structure makes it perfectly stable. This in no way applies to lateral systems used to stiffen girders, or to cross frames.

The question as to what construction of guards is the most useful seems to be one of great importance and interest to all who are concerned in any way with elevated roads. On the lines under consideration a 6 x 6-inch inner guard is used, while the outer one is 6 x 8 inches. Would not a 6 x 8 inch be better for the inner rail? Without doubt, it is the more important of the two, and should the car jump the track, more lifting power would be necessary to carry it over the high rail than the low. It is true that in case of a blow the high rail would be more likely to split than the low, yet it would seem very doubtful if a blow of that severity could be produced on the inner rail, which is but 4 inches from the track rail.

The outer guard to a large extent is a matter of sentiment. Its only practical use can be that it stiffens the outer ends of the tie and might in that way prevent a wreck. Could the outer guard be placed far enough from the track rail to allow the entire right wheel of the car to pass over the inner guard before the left wheel struck the outer guard, its practical use would be established. As this is not possible in present construction, the matter need not be discussed. The outer guard, however, lends an appearance of security for the traveling public which possibly warrants its use.

By Lee Treadwell, M. Am. Soc. C. E.

Few engineers will deny the fact that an elevated railroad should be built, not only to carry the assumed live and dead loads, but also to resist the longitudinal thrust of braked trains, the centrifugal force of moving loads on curves, and a lateral force on tangents due to wind pressure and the oscillations of moving trains. At the same time, however, each designer will probably have his own ideas as to how the longitudinal forces should be distributed. Judging from most of the elevated roads now in existence, it would seem that the general practice has been to assume that the track and guard rails make the structure continuous over the expansion joints, and therefore, that the longitudinal thrust of braked trains is distributed over a long stretch of track. It is true that the track and guard rails do give to the structure a certain amount of continuity, but it is an uncertain factor and should not be counted upon, except in special cases. The author's method of treating that portion of the structure between expansion points as entirely independent and separate, and in designing it to resist all the forces that can be applied between those points, is undoubtedly to be commended; in fact it would seem to be the most scientific way of solving the problem. Granting, however, that so far as strength is concerned, the track does make the structure continuous, the author's method would still be preferable, for it leads to the attainment of one of the most desirable qualities in an elevated railroad, namely, that of rigidity.

Again, few will question the author's statement that an elevated railroad should be built with the same degree of excellence in respect to quality of material and workmanship as that of any railroad bridge, and he is probably not going too far when he intimates that it might be well to make the details and connections even more nearly perfect in the former than in the latter. The reason for this is, as stated in the paper, that a railroad bridge will generally receive its maximum live load at comparatively long intervals only, while in the case of an elevated railroad the assumed maximum live load may be applied many times a day. Another reason why the greatest care should be taken in detailing an elevated railroad is that owing to the frequency of the trains, it is in an almost continuous state of vibration and tremor, which tends to work the connections loose and weaken the structure.

In respect to the use of "unreamed soft steel at a low intensity of working stress, or reamed medium steel at a higher intensity," the author shows his good judgment in his final decision to use medium steel throughout. If, however, it be claimed that rigidity is one of the essential qualities of an elevated railroad, it must be admitted, also, that the use of "soft steel at a low intensity of working stress" has at least one advantage over "medium steel at a higher intensity." The advantage depends on the difference in the unit strains used, for, as the elastic co-efficients of the two metals are equal, the deflections and consequent vibrations will be in direct proportion to the fiber strains used in designing. It necessarily follows, therefore, that, everything else being equal, the lower the unit strains used, the more rigid will be the structure.

It is also claimed by some engineers that soft steel is better suited than medium steel to resist suddenly induced strains; and for short-span bridges in particular, the use of the softer metal is urged. The author himself half admits these claims to be well founded. Then, if it be true that the nature of soft steel is such as to make that metal more reliable than medium steel under shocks of greater or less intensity, it would only seem proper under those conditions to strain the two metals about alike, up to, say, 8,000 or 10,000 pounds per square inch, assuming that the advantage gained in the softer quality of one metal is sufficient to offset the greater elastic limit of the other. If it be taken for granted, also, as claimed by many manufacturers, that the reaming out of the cracked metal around punched rivet holes does not materially increase the strength of the section, and especially its elastic limit, then soft steel would seem to be an ideal metal for an elevated railroad, and there would undoubtedly be a considerable saving in cost by using it in preference to reamed medium steel.

In the writer's opinion most of the advantages claimed for soft steel are entirely problematical, and, except for special purposes, he does not advocate its use. In point of endurance it has been pretty well demonstrated among mechanical engineers that soft steel is far inferior to a higher carbon metal; and there seems to be no good reason why civil engineers should not profit by the experience of their mechanical brethren. Take, for example, car axles, crank shafts, piston rods, and steel rails—how is it that they manage to stand up so well when strained in almost every conceivable way? Does not the chief reason lie in the fact that they have a high elastic limit and ultimate strength? That is certainly the most plausible explanation. It may be claimed that car axles and crank shafts are made of a better quality of metal, which is improved by forging; but, however that may be, the same can hardly be said to be true of steel rails, for they are rolled from Bessemer steel, and have an elastic limit usually not below 50,000 pounds per square inch. It would seem to follow, therefore, that, other conditions being the same, the capacity of steel to resist indefinitely the application of externally applied forces without injury to itself is measured by its elasticity. The higher the elastic limit, the greater are its resisting powers and the longer will be its life.

Why, then, it may be asked, is soft steel so often called for? One reason is, that some engineers believe it more nearly approaches the nature of wrought iron, and that it is, therefore, more suitable for short-span bridges; in other words, that it is more reliable than medium steel under shocks and suddenly induced strains. As before stated, these claims do not seem to be thoroughly founded on facts. Actual experience with both metals under heavy strain, especially in the field of mechanical engineering, where the wear and tear is more easily observed, is constantly adding proof of the inferior quality of soft steel as a durable and serviceable metal.

Another and probably more important reason why unreamed soft steel is so widely favored is due to two facts; first, it is cheaper pound for pound than reamed medium steel; and, second, most manufacturers favor its use because it is claimed to be easier to make and easier to manipulate in the shop. Taken as they come from the rolling mill, there is practically no difference in the cost of the two metals, but in the shop it must be admitted that the softer and more pliable a metal is, the easier and less expensive are the operations of straightening and punching. The difference in manipulation is so slight, however, that most manufacturers will bid the same pound price on unreamed work whether it be of soft or medium steel. Nevertheless, pay the contractor the added cost of straightening, punching and reaming, and he would still rather use soft steel and punch the rivet holes full size, simply because the operation of reaming retards the progress of work in the shop, while his interests require that it be pushed through in the shortest time possible. It is a business proposition that no contractor can afford to ignore in these days of strong competition, especially when there is a large demand for work to be delivered in a limited time. If the manufacturer be paid for the extra work of sub-punching and reaming, it is not clear why he should oppose it on any other grounds than that it reduces the output of his shop. Conditions are changing somewhat, though, and fewer objections to reaming are heard now than formerly. Most of the leading bridge companies are well equipped for drilling and reaming, and they are still making improvements in their equipment along that line. The chief engineer of one of the larger companies told the writer recently that the reaming capacity of his shop was about equal to its riveting capacity.

How much cheaper is the finished product of unreamed soft steel than reamed medium steel? According to the author, the cost of reaming varies from one-tenth to two-tenths of a cent per pound. To illustrate further, suppose bids to be invited on 1,000 tons of structural work erected and painted, first, on unreamed soft steel; and second, on reamed medium steel. The bidders would make less than 10 per cent. difference in the pound prices for the two metals. The author states, also, that reamed medium steel may be strained 10 per cent. higher than soft steel. Some specifications allow 15 per cent. difference. The author's statement, therefore, that "as far as the total cost is concerned, it is immaterial whether unreamed soft or reamed medium steel be used," is rather conservative than otherwise in favor of the latter metal. Then there still remains in favor of medium steel the advantage gained in the superior workmanship due to reaming; such, for instance, as the perfect matching of rivet holes in the main members and the consequent better fitting of all the parts. It is self-evident that the more nearly perfect the joints and connections of any structure are fitted together, the more rigid and durable it will be.

By soft and medium steel, the writer refers to metals having average ultimate strengths of 56,000 and 64,000 pounds per square inch, respectively. It may be added that no such distinction is observed by the majority of rolling mills. With them the limits govern rather than the averages called for in the specifications. In specifications for soft steel the ultimate strength is generally limited to 60,000 or 62,000 pounds per square inch, while for medium steel it is generally required that the ultimate tensile strength shall be not less than 58,000 to 60,000 pounds per square inch. Here there is a maximum overlap of 4,000 pounds per square inch. The engineer who wrote the specifications for soft steel could not be persuaded to change to medium, and the designer who called for medium steel would be highly indignant if asked to accept the softer metal instead. The truth of the matter is, however, that many of the mills are daily filling orders for both specifications from practically the same grade of metal. Its ultimate strength averages from 58,000 to 62,000 pounds per square inch, and as the limits of neither specification are transgressed, both the engineer and the designer are well pleased with what they get.

This practice on the part of the rolling mills of striking an average between soft and medium steel, rather than any lack of uniformity in the basic open-hearth product, is possibly responsible for the facts which led the author to state, that "the reports of the company's inspectors indicate that the basic steel is not quite so uniform in quality as the acid; and that it may prove advisable in future specifications for basic medium steel to reduce the average ultimate stress limits from 64,000 to 61,000 pounds per square inch."

Excluding metal rolled for rivets, it is probably safe to say that 90 per cent. of the soft and medium steel rolled at the present time for structural purposes has an ultimate strength between the limits of 56,000 and 66,000 pounds per square inch, a range of only 10,000 pounds which some manufacturers claim should be allowed.

It is possible, then, that authors of specifications are splitting hairs and quibbling over the difference between soft and medium steel to no purpose. It is to be hoped that such is not the case, but it must be confessed that there is some ground for such a declaration. Why not adopt a single standard at once and be done with it? There are three courses open; first, accept and be contented with the present imperfect system; second, retain the distinction between soft and medium steel, but require that the metal furnished shall have an ultimate strength equal to that called for in the specifications, and not an average 2,000 or 3,000 pounds above or below; third, abandon the distinction between soft and medium steel, and adopt, for all general purposes, a uniform metal of the highest grade the manufacturer can make consistent with the cost, regularity and reliability of the product. At present, an average ultimate strength of from 60,000 to 62,000 pounds per square inch would probably be about right. It would be necessary, of course, to continue to make rivets of soft steel; and for very long span bridges it would be advantageous to use a higher grade of steel, having an ultimate strength of, say, 62,000 to 70,000 pounds per square inch, even if the cost should be increased somewhat.

If it were proposed to abandon the present distinction between soft and medium steel, there would probably be a vigorous protest from the engineeering profession in general; but, however that may be, much may be said in favor of a single standard for structural steel. In the first place, the difference between the ultimate strength of such a standard and the ultimates now called for in specifications for soft and medium steel would be insignificant when reduced to the corresponding working stresses, especially when it is remembered that authors of specifications differ greatly in the unit stresses allowed in designing.

Again, if a single standard were adopted, the manufacturer would doubtless feel disposed to improve his metal in the direction of a higher elastic limit, and at the same time preserve its uniformity and toughness; but so long as he is required to make both soft and medium steel upon specifications that overlap, so long will the metal produced be neither soft nor medium steel in the strictest sense, but an approximate average between the two. Then, too, if the manufacturer were required to make only one grade of metal, it would naturally be more uniform and regular in quality, which would tend, also, to decrease the cost of manufacture slightly.

In speaking of the relative merits of acid and basic open-hearth steel, the author states that "the reports of the company's inspectors indicate that the basic steel is not quite so uniform in quality as the acid." During the last two or three years it has been the writer's privilege to spend considerable time in the shops of some of the leading bridge companies, and, in addition to observing closely the various manipulations the metal must undergo before it is finished ready to ship, he has conversed more or less with those who are familiar with the conduct of the metal at every stage of its manufacture. The information gained in this way, added to the results of the testing laboratory, tend to convince him that the product of the acid open-hearth furnace is somewhat superior to that of the basic furnace, notwithstanding the claims of some of the manufacturers to the contrary.

In the first place it is perfectly rational that acid steel should be better, for it is more homogeneous in its molecular construction. When properly manipulated, it does not require to be recarbonized. Basic steel, however, is first run very low in carbon so as to reduce the amount of the impurities in the metal, and especially to lower the percentage of phosphorus. It is then recarbonized, and to perform that operation so as to obtain a thorough, complete and even distribution of the carbon throughout every particle of 25 tons of metal in one mass is practically impossible. It must be admitted, though, that such a high degree of perfection has been obtained in this direction that it is exceedingly difficult to distinguish the two metals in the ordinary laboratory tests. If a large number of full-size members were tested to destruction, it is possible that the difference would be more noticeable. For instance, in the test to destruction of full-size eyebars of considerable length, it has been observed that the stretch as measured foot by foot is noticeably more uniform in the case of acid than in that of basic open-hearth steel. This fact alone would seem to prove that the former metal is more homogeneous than the latter.

With respect to the different melts or heats, however, it is believed that basic steel can be made just as regular in quality as the acid product, and possibly more so. The reason for this is the fact that in the case of the former, the quality of the metal can be regulated in the furnace by reducing the percentage of the impurities, and then by reintroducing the proper amount of carbon; but in the case of the latter, the quality of the metal depends on the purity of the stock charged into the furnace. In fact, owing to the oxidation of a certain portion of the iron, the percentage of the impurities in the final product is greater than in the original stock or scrap. About the only thing that it is attempted to regulate in the acid furnace is the percentage of carbon, but if it is run too low in the finish and has to be recarbonized, the product is inferior to basic steel. Probably the best quality of acid steel is that made from basic scrap containing small percentages of sulphur and phosphorus, with enough pig iron added to regulate the carbon. In one sense, therefore, acid steel is basic steel refined.

Reasoning along these lines, and not forgetting the results of the testing laboratory, it is difficult to understand how it is possible to produce basic steel superior to or even equal in quality to acid steel, provided the same degree of care and precaution is observed in the manufacture of both metals.

Assuming that acid steel is somewhat better than basic, it is largely a matter of cost whether the difference is great enough to warrant any decided preference being given the former. Acid steel being made principally from selected scrap, its first cost would be considerably increased if there was a large demand for it in preference to basic steel. In view of this fact alone, it is probably more economical in the end to use the basic product, especially if the ultimate strength required is not greater than 65,000 pounds per square inch. For metal with an ultimate strength above 65,000 pounds per square inch, the writer would give a decided preference to the acid product.

When it comes to sub-punching and reaming in general, much may be said pro and con. It is a subject on which there will always be a difference of opinion among engineers and manufacturers. The writer agrees with the author that it is just as essential to ream soft steel and wrought iron as it is to ream medium steel; for, so far as the elastic limit of the metal is affected, one is injured by punching, relatively, about as much as the other. Then, too, it is almost impossible to make long rivets fill punched holes completely, even when the greatest care is taken in heating and driving the rivets. Where the rivets are short, they can be made to fill the holes quite well, if properly heated.

The metal-work with the rivet holes punched ⅛ inch less than the diameter of the cold rivet and reamed to the required size after the several parts have been assembled, or to cast-iron templets, is better than work with the holes punched full size and often badly matched few will deny, but whether it is always better to the extent of the added cost of reaming is a very different question. The writer is in favor of sub-punching and reaming, and particularly so when applied to heavy and important structures, but he does not deem it essential to ream "all metalwork." That high standard of perfection in workmanship might be very desirable, but owing to economic considerations, he believes there is a large class of light work in which it is perfectly allowable and even advisable to omit sub-punching and reaming, at least in those cases where the metal does not exceed ⅝ inch in thickness, and where the rivets pass through only three or four thicknesses of plate.

It is not practicable to lay down an inflexible rule governing sub-punching and reaming. Each designer will have to depend on his own judgment in the matter, being guided at the same time by the importance of his structures and the funds at his disposal; but in case of doubt, his decision will always be a safe one if cast in favor of the higher grade of workmanship.

Probably the most valuable feature of the paper is the illustration, description, and estimate of the weight and cost per lineal foot of each of the thirteen designs worked out by the author. It is interesting to follow the comparison made between the different styles of construction, and to note that the best form, namely, that with braced towers, is the cheapest. One noticeable feature of all the designs is the ample provision of bracing to prevent secondary stresses due to longitudinal and transverse forces. When tower bracing is used, the necessity for fixing the tops of the columns in the direction of the longitudinal axis of the structure is not apparent. Such a fixed condition of the column only augments the temperature stresses without gaining anything in point of strength or rigidity. When the tower bracing cannot be used, however, it is certainly advantageous to fix the columns at both top and bottom.

Another noticeable feature of the author's design is the extension of the columns up to the top of the transverse girders. Whatever may be said against this practice, it certainly has the advantage of greater strength and rigidity. The sections of the columns themselves could hardly be improved upon, at least so far as strength and rigidity are concerned.

By Charles V. Weston, Esq.*

The importance of maintaining a high standard in respect to details and workmanship for elevated railroad construction cannot be overestimated, and the writer fully concurs in the author's statement that an elevated railroad structure is just as important as any railroad bridge ever built, because the live loads are frequently applied, and the assumed maximum loads very nearly reached many times each day. The elevated railroad

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*Chief Engineer, Northwestern Elevated Railroad.

designer should seek to obtain a structure combining the greatest possible rigidity, with economic distribution of metal. This cannot be accomplished except by the most careful detailing and excellence of workmanship.

Sub-punching and reaming of rivet holes has been rigidly enforced throughout the Northwestern and Union Elevated Railroad work, and the results as indicated in the completed structure have removed from the writer's mind any doubt which may have existed with respect to the advisability of specifying and enforcing sub-punching and reaming for elevated railroad work. Reaming is the only method which will insure an exact coincidence of the rivet holes in the component pieces of the various members of the structure.

The author's statement in regard to the bearing power of Chicago soil seems to the writer to be misleading, and tending to leave the impression that the foundations for the Northwestern and Union Elevated Railroads were designed and constructed for a unit load upon the soil of 1 ton per square foot. The writer has had much experience in excavating and building foundations upon the soil underlying Chicago, and he has seldom encountered, except near the banks of the river, a soil which would not safely support a load of 3,000 to 4,000 pounds per square foot. At least two-thirds of the Northwestern Elevated Railroad line is located through a sandy district where the soil would safely support loads of 8 tons to 10 tons per square foot. Through this sandy district the foundations were proportioned for unit pressures of 3,500 to 5,000 pounds per square foot, the actual cost of foundations being greatly reduced below the estimated cost.

Every feature of the detailing of the Northwestern and Union Elevated Railroad structures has been very carefully considered, and the result in respect to rigidity of structure and economic distribution of metal is very satisfactory. If the writer were called upon to participate in the design and construction of another elevated railroad, he would not deviate from the principles which have been followed in the design of the Northwestern and Union roads in Chicago. One detail of these designs he would change, viz., the position of the top chord of the longitudinal girders, with respect to the top chord of the cross-girders. As shown on the drawings, the top chord of the cross girders projects from 1¼ to 3 inches above the top chord of the longitudinal girders. This detail seriously interferes with the uniform spacing of the track ties, and will increase to some extent the difficulties of renewing the track. Track girders should project at least 1 inch above cross girders, which insures absolutely uniform spacing of the track ties. When one reflects on this subject it is seen that the entire structure of an elevated railroad, from the foundation to the top chord of the track stringers, is expressly built for the purpose of obtaining a perfect track, and the importance of preparing an absolutely unbroken surface for that track is apparent.

By G. Lindenthal, M. Am. Soc. C. E.

Three points occur to the writer in reading the paper. They are in connection with the stairways, station platforms and the aesthetic considerations.

The subject of proper stairways does not fail to impress itself forcibly on every passenger. To the writer's knowledge there is not in this country a single elevated railroad, including the one that the author designed, of which the stairways are proportioned with thought of real comfort in ascending or descending them. The daily blockades in the stations during the rush hours testify to it. The cause for them is plain. The average person, leisurely walking on the level, covers about 30 inches with each step. To prevent a blockade, that horizontal velocity should be maintained on the stairway during the descent or ascent of about 20 inches, equal to about three stairway steps. The leg motion for that purpose would have to be three times as fast on the stairway as on the level, involving some athletic skill of which the average passenger is not possessed. Hence the blockade. The proper remedy for it is to make the stairway three times as wide as the passage at the top leading to it, so that the crowd on descending can spread out sideways. The broadest stairway should always be provided for. It should not be more steeply inclined than in the proportion of two horizontal to one vertical. A very convenient proportion is 6½ inches rise to 13 inches tread. On all the elevated railroads the stairways are much too steep, and in wet and frosty weather positively dangerous.

One of the worst examples of badly proportioned stairways was in the first elevated Broad Street Station of the Pennsylvania Railroad in Philadelphia. The first week after completion, so many persons fell down stairs, threatening the railroad company with suits for damages, that it was found necessary to build over the narrow marble steps wooden stairways with less slope and a more convenient proportion of rise to tread. The stairways in the present Broad Street Station are very comfortable and properly proportioned, and good examples of what stairways should be for large crowds.

The separation in the station of the incoming and outgoing passengers is not dwelt upon by the author with sufficient emphasis, although his stations show an attempt to meet that requisite. In nearly all railroad stations and in all elevated railroad stations in the East, the incoming and outgoing passengers are in constant collision. It shows a discreditable want of forethought and study.

Making the trains and tracks noiseless, or nearly so, should be one of the principal concerns of the engineer, whether the law requires it or not. That it must necessarily add to expense, as the author intimates, is a view which the writer does not share.

In mentioning aesthetics in connection with engineering structures, the author touches a subject little appreciated by many engineers. It may be that because the conception of beauty never was and never will be one capable of precise definition, the engineering mind, accustomed to dealing with concrete matter in precise and scientific ways, has become incapable of judging good architectural appearance in connection with structures. Some engineers' ideas of beauty are running to curves and those of others to straight lines; some claim any structure to be beautiful which is properly proportioned in strength and otherwise well adapted to its utilitarian purpose, and others desire their constructions to be called beautiful, conceived as tools doing their work, and to be classed presumably in the same architectural category with crowbars and wedges. The confusion of ideas of beauty is clearly apparent in what the author says on this point: "The extra cost of decorating an elevated structure is considerable," and as proof thereof plans of an elevated railroad of that supposed higher architectural order are shown, in which riveted railing brackets are hidden under ornamental cast-iron consols, resting on air, in which supremely superfluous arches are abutting against slender posts, set off with Moresque caps and pedestals, in which the panels are fitted up with (in such place) meaningless scroll work, and in which lions' heads are impaled on the ends of water spouts. No wonder that projectors of good taste and sense should refuse to grant a dollar for this kind of aesthetics.

It is unfortunately a frequent fact that prominent engineering structures, after having their proportions and lines fixed with the usual inanity and indifference to harmonious and pleasing ensemble, are handed over to some decorator, who is to make it artistically acceptable, according to the amount of money that the owners may be persuaded to spend on so-called aesthetics. There are some such examples in New York, and there are to be more in one or two projected large bridges.

The author should be credited for also saying: "The careful designer can generally manage to make his construction more or less sightly, without adding materially to expense.". To which should be added, that it is the essence of the highest engineering skill to give a construction a pleasing appearance and agreeable character, without the addition of unnecessary parts and with the simplest means.

Without skill and thoughtful study a perfect work in that respect cannot be designed. The road to perfection is here, also, from the complicated and unsightly to the simple and aesthetically correct. Intimate knowledge of manufacturing methods is as essential for exercising that skill as freedom from construction and manufacturing bias. For the want of the latter condition, an architecturally meritorious design for an engineering structure may not readily be expected to issue from a manufacturing or contracting establishment.

The author invites criticism as to whether he succeeded in giving the structure for the Northwestern Railroad in Chicago a pleasing appearance. The writer will point out merely for illustration one feature. For every five or six spans there is a braced bent with shallower girders and with stout diagonals to afford longitudinal rigidity. With the technical reasons for this arrangement the writer fully agrees, but the break in the continuity of the beam or girder line at the bent is decidedly unsightly and unnecessary. The observer, except he be a bridge specialist, is not acquainted with, and does not care for, the finesse of bending moments and shearing strains, which prompts the utilitarian engineer to use a shallower girder and to break the continuity of line. It is too unimportant a reason to the beholder, who experiences the disagreeable sensation that something is the matter with the superstructure at that bent. He can readily understand the purpose and admit the propriety of the bracing every four or five spans, but to his mind uniform strength of the roadway in this structure requires uniform beam height. The unity of appearance is violently interrupted to save a few dollars' worth of iron, which if not saved makes the structure so much stronger and evidently better looking. No amount of cast-iron ornamental brackets and scroll work, put on by a decorating architect, could make up for such fault of the engineer, if a high aesthetical structure, of the kind before mentioned, were to be made of it.

Another unsightly feature, not difficult to avoid, is the track with the ties sticking out into the air, and giving the structure a ragged and uncouth appearance.

The natural black gray color of iron gives the impression of a strong and serious material, the appearance of which cannot be improved by colored paints. Preserved by oiling and varnishing, the natural color of iron is an essential part of its aesthetical appearance. Dust and rust are easiest discovered on it, and therefore most easily guarded against by timely repairs or reoiling. In rare cases, a colored paint may be more suitable, as, for instance, in wire cables covered with white paint. They absorb less heat from the sun and appear of larger diameter than with a dark color. Some parts of the New York Central Railroad viaduct on Park Avenue in New York are good examples of simple unadorned iron architecture, although in other respects it is not commendable, as it is atrociously noisy.

In connection with aesthetics in engineering structures it is opportunely interesting to note what the venerable German savant, Prof. Reuleaux, said in his well-known blunt manner in a recent paper* on modern bridge construction.

"I do not regard in proper taste extra ornamentation or attached decorative features, or style subsequently furnished by an architect. By architectural designing, I mean the choice of the principal forms, the disposition of the masses, the arrangement of the lineaments of the structure.

"We are asked to call (das zweckmaessige) the suitable or fitting for its purpose beautiful; if this be so, we would have to regard a human skeleton as beautiful, because it is adapted for its purpose in a wonderfully high degree. But it does not give us the sense of beauty; on the contrary, it only fills us with aversion.

"The objection to this criticism might be made that the skeleton has no life, and that it lacks the rounded outlines of living flesh. But if in this respect the suitable to its purpose were always beautiful, then we would have to admit that a Hottentot Venus is beautiful; she is healthy, and she is not lacking in flesh, which we miss on the skeleton, and her build is eminently suitable, in that the dusky mother carries on her posteriors, projecting 30 centimeters, her youngest offspring, nourishing it at the same time. I doubt very much whether even the defender of the utilitarian will claim beauty for her on that account.

"We old scholars belonging to the past call that beautiful in a being or in a structure which shows a certain harmonious combination of intellectuality with matter. In that way we have inherited through ages a conception of beauty which is not easily defined by words, but which anyone may appreciate, although he may not be able to create it."

By George H. Pegram, M. Am. Soc. C. E.

The writer agrees with the author that medium steel with reamed holes should be used in preference to soft steel without reaming. Indeed, it would be better to require reaming all punched holes in steel which is to be placed in structures where it will be highly strained or liable to receive

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*See Glaser's Annalen, February 1st, 1897.

blows. If the object is to get fair rivet holes rather than to remove the injured material around the hole, the rigid reamers recommended by the author are, of course, preferable, but the flexible reamers will remove the injured material more uniformly about the axis of the hole, and, the writer believes, will give generally good results.

An elevated railroad structure should be of the best character of bridge-work. Elevated roads are always built where the ground is valuable, and proper economy would seem to demand a two-column bent in preference to one of four columns, in order to leave the ground available for other uses as far as possible. This would also apply to braced towers. They no doubt give stiffness to the structure in a much cheaper way than any other, and where the ground can be spared for this purpose it is well to use them; however, experience shows that they are not necessary.

The writer has always believed that cross-ties are out of place on an elevated structure. On the ground, where they are necessary to distribute the weight over the surface, they have proved the best construction, but they are not needed for this purpose on an elevated road, and their effect there is to darken the street below, to intensify the noise, increase the labor of cleaning the structure, and lead to unpleasant drippings after a fall of snow or rain.

The writer submits in Fig. 37 a drawing of the superstructure of the Kansas City elevated road designed by him and built in 1886, in which the rails are carried in iron troughs which also acted as the top chords of the trusses. These channel chords serve also as guard rails, and in case of breakage of a wheel or similar accident, are in effect parallel skids on which the trucks, which should be provided with bolsters located but little above the tops of the channels, might slide. In order to take up as little of the street as possible, the spans were made about 50 feet; the total weight of steel per lineal foot is 478 pounds. Pin connections were used in this structure, as it is the writer's belief that a structure with much less ugliness and obstruction of light can be built with pin connections. It can be also strengthened with less injury to the remaining parts, and experience has shown that, where properly designed, it is quite as durable. The writer submitted a plan similar to this for the Hoboken elevated road in 1883.

By C. L. Gates, M. Am. Soc. C. E.

Regarding medium versus soft steel, the writer's experience would lead him to prefer soft steel punched over medium steel reamed if the difference in unit stress is assumed at 10 per cent. While it may be right to select medium steel for structures under light traffic, such as that imposed by street railroads, as recommended by the author, the writer does not favor any extensive use of this grade of metal for ordinary railroad traffic except for truss members of long spans which take their maximum stress gradually, and certainly never for short girders subjected to the heavy pounding and vibration of heavy freight trains. The more liberal distribution of

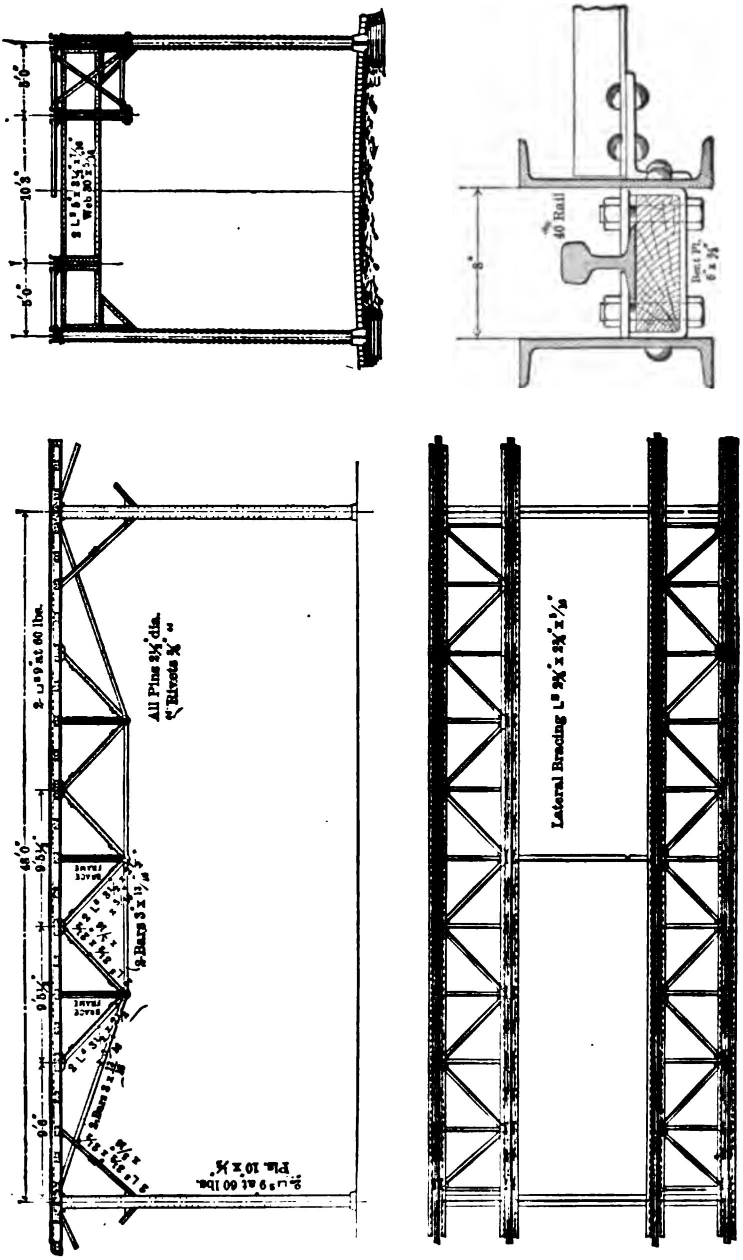
8'0"
10'3"
8'0"
2 L^s 3½"x3½"x7/16"
Web 30"x5/16"
40 Rail
8"
Bent Pl. 6"x⅜"
2-[^s 9" at 60 lbs.
All Pins 2½" dia.
⅞" Rivets ¾"
48'0"
9'5½"
9'6"
9'5½"
9'6"
2-Bars 3x13/16
Lateral Bracing L^s 2½"x2½"x5/16"
2-[^s 9 at 60 lbs.
Pls. 10x¼"

FIG. 37.

metal at a low unit stress seems to be more desirable, and the softer steel more preferable than the more brittle and higher grade of steel; and, if there be any need of reaming at all, by all means let all work be reamed, especially when the thickness of metal exceeds $\frac{5}{8}$ inch.

As a matter of economy, there may be a leaning toward medium steel at a high unit stress for structures located at a great distance from the points of manufacturing and center of distribution; but for the Central States soft steel at a low unit stress will no doubt be used in the future.

Greater care is taken by shop men in matching rivet holes of component pieces of long members, when they know the work is not to be reamed, than when the requirements of specifications call for reamed work. In the former case, if punching is done by piece work the reaming over of misfits has to be done by and at the expense of shop men, and thus they find it to their interest to do good work. With the multiple punch and spacing table very accurate work is done in the shop the writer is connected with, so reaming can generally be dispensed with, notwithstanding the assertion of the author to the contrary.

In this connection, the writer would assert the prediction that for the bridge structure of the future, if not of to-day, good specifications will require that every piece of soft or medium structural steel, and certainly all subject to tension in the finished member, shall be thoroughly and uniformly annealed after the process of straightening and punching has been completed and before riveting is done, for obvious reasons.

As regards the use of basic open-hearth versus acid open-hearth steel, it would be profitable for the profession to hear from the steelmaker direct on this subject. While some inspectors are inclined toward a preference for acid open-hearth steel, owing to the apparent higher elastic limit, yet it must be admitted that in accepting acid steel a minimum of 0.08 per cent. of phosphorus must be conceded, while for basic steel it is safe to specify as low as 0.05 per cent. for phosphorus, and one can generally rely on obtaining as little as 0.02 per cent or 0.03 per cent. Phosphorus being known as the great enemy of good steel, especially in cold climates or where it is subject to sudden changes to very low temperature, this fact alone, in the writer's opinion, should lead to the more general preference of basic open-hearth steel, more particularly when the market price of the product is taken into consideration.

Referring again to design, the author has certainly shown a happy solution in solving in an economical manner the problem of bringing wind stress or train vibration to the trestle posts, thus relieving the generally much-abused end beam from excessive longitudinal bending strain. The writer does not agree, however, with the author's preference for the four-post bent for a four-track railway. All bents of an elevated railway must necessarily be an obstruction to the established street traffic at the lower or ground grade, and a four-post bent certainly offers more serious objections on that account than a two-post bent; this is slightly intensified when first cost is in favor of the two-post bent. Another objection to the use of a four-post bent is that the foundations of the four pedestals are liable to different settlements under load, thus causing ambiguous stress in the main beam. for which this member is not generally proportioned.

By A. T. Tomlinson, M. Am. Soc. C. E.

The author has evidently given much thought and study to the several designs for elevated railway structure discussed in his paper. The design adopted was chosen entirely on account of its superior rigidity, adaptability to the different conditions to be met and aesthetic effect, and without regard to the difficulties which would arise in laying, and later on, in maintaining, the track.

In the designs chosen for both four-track and two-track structure, the transverse girders project above the longitudinal stringers from ¾ inch in the double-track to 3 inches in the four-track. This is not a material objection on straight track, but it will be readily seen that on curves where it is generally impossible to set all the transverse girders radially, and where frequently some of the transverse girders make very acute angles with the center line of the track, the conditions are bad. The ties must be laid parallel to the transverse girder, or if laid radially, they will have to be fitted over the transverse girder, materially damaging the tie and rendering replacement very difficult.

The author's original specifications called for 6 x 8-inch ties laid flat and spaced 14 inches center to center. This was changed on the first track laid on Lake Street from Market Street to Wabash Avenue to 15 inches center to center, in order to bring the ties out even at rail joints. This track was laid without tie-plates. After the adoption of the Servis tie-plate, the spacing was increased to 18 inches on straight track, retaining the 15-inch spacing on curves and cross-overs.

The objection to wide spacing of ties, and the author's reason for specifying 14-inch spacing, is that in case of a derailment there is a strong tendency for the ties to bunch. This, in the writer's opinion, is not a valid objection, as the ties are firmly bolted to the longitudinal stringers, and each tie is securely bolted to two of the four guard rails, to the inside and outside guards alternately. Many elevated railroad accidents have come under the writer's observation, but in none of them has he known the ties to bunch.

By spacing 18 inches instead of 14 inches, a saving of 22¼ per cent. is made in ties, tie-plates, spikes, bolts, washers, etc., which is no inconsiderable item, being at least $1,000 per mile of single track for ties alone, and probably $1,000 more per mile for fittings and labor of laying track, to say nothing of the eventual cost of replacement.

The lumber used in the track is long-leaf southern yellow pine, vulcanized. The writer thinks a mistake was made in specifying that absolutely no sap would be allowed. In the first place, if 1 inch of sap wood had been allowed on two corners of the ties, guard-rails and heavier joists, the cost would have been reduced, but more important than this, is the fact that in almost every piece of dimension lumber, the heart of the tree and center of stick are generally coincident; consequently, whichever side is laid downward, the upper side checks badly. Had a small amount of sap been allowed, the heart side could always have been laid downward, and splitting on account of weather have been reduced to a minimum.

The author originally specified an 80-pound rail in which the metal was distributed as follows: Head, 47 per cent.; web, 20 per cent.; flange, 33 per cent. The rail finally adopted was one which was already standard on the Lake Street Elevated Railroad, and known as No. 8001 in the Illinois Steel Company's book of rail sections. This section varies but slightly from the standard 80-pound rail, designed by a committee of the Society, and having the metal distributed as follows: head, 42 per cent.; web, 21 per cent.; flange, 37 per cent.

In the track now being laid on the Union Elevated Railroad, and to be laid on the Northwestern Elevated Railroad, 60-foot rails will be used, connected by Weber rail joints, using four ¾-inch Harvey grip bolts, the joints suspended and breaking even, except on curves, where the joint of one rail is placed as nearly as possible opposite the center of the other rail.

By Samuel M. Rowe, M. Am. Soc. C. E.

The Northwestern Elevated Railroad Company directed experiments to be made to test various paints as to their relative ability to protect metal-work against atmospheric action, and particularly against the gases produced by the combustion of coal, with which the atmosphere of the city is more or less pervaded. Each paint was tested by applying it to four steel plates, three coats on each plate. Some of these were exposed to smoke and steam from locomotives, and others to the smoke of bituminous coal in a box prepared for that purpose. Neither of these methods were carried on long enough to furnish decisive results, but the condition of plates exposed to the atmosphere was observed at intervals during a period of two years.

The dark mineral paints were found to retain their color best, the effect of the weather on the oils being less than where lead and zinc were used as pigments. The use of graphite with white lead and zinc apparently gives the most permanent light shade.

In determining the adhesion of paint to metal, a toothed chisel was found advantageous. The blade is ¾ inch wide, one-half toothed with $\frac{1}{32}$-inch notches, $\frac{1}{16}$ inch apart, and the other half with $\frac{1}{64}$-inch notches, $\frac{1}{32}$ inch apart. If the paint is loose or easily parted from the metal, this will be at once manifested if it is attempted to shave a strip of the paint from the metal; the surface of the latter will be free from paint and show any rust spots which may have formed in consequence of the damaged condition of the covering. If the paint is very brittle, the whole surface will be stripped clean, whereas if it is tough, elastic, and clinging closely to the metal, each notch in the tool will leave a fine, continuous line of paint.

The durability of paint and the thoroughness of the protection it affords to the metal depend largely on the resistance of the surface and body of the paint to the action of the weather. If the surface changes or loses its density, the body of the paint will soon do the same, and the whole become porous, absorbing moisture and opening a way for rust. The best degree of elasticity and toughness in the paint seems to be that which will prevent breaking or checking by alternations of the temperature to which it is exposed and from the usage to which it is subject. A tough, elastic paint will roll before the tool and form a wad which will feel like soft leather when rolled between the thumb and finger. A hard, brittle paint will crumble into dust.

Some of the paints tested were soft and sticky when exposed to a summer temperature after the lapse of two years, a condition undesirable in any paint except one exposed to a combination of locomotive steam and smoke, one of the most destructive agents to be withstood. Some of the Chicago viaducts suffer severely from this action, the metal of the lower chord and floor systems being eaten away so rapidly as to require the renewal of these parts long before the less exposed portions of the structure are affected materially. In such cases anything that will withstand the action of the gases on the metal is invaluable. Neither time nor means were available to analyze these paints to determine the cause of the different results, but it has been suggested that the use of animal fats with the oils may produce the softness mentioned, while insoluble or very refractory gums of some kind may help to produce toughness and firmness, when combined with linseed oil.

The asphaltum paints harden like glass, forming a surface which seems to resist the action of the coal gases perfectly, but they are liable to check and do not cling to the metal, being easily broken and separated from it. The Eureka paint used by the author on the Wabash Extension structure covers and clings well to the metal, holding its color fairly, but when shaved with the testing chisel, it is hard and brittle, and seems to some extent porous and likely to absorb moisture.

The author's suggestion to give one coat of linseed oil to all work before it leaves the shop is a good one, and a complete immersion of each piece after it was thoroughly cleaned would be still better. By this means parts would be reached which will be inaccessible for painting afterwards.*

The question of the bearing qualities of the soils in Chicago, with reference to foundations for an elevated railroad, is one that requires investigation somewhat in detail, as there is a great variation in its character in the different parts of the city. That district traversed by the Union Loop, Wabash Extension, South Side Rapid Transit and part of the Northwestern elevated lines, consists of sand, gravel, or both in varying quantities, while part of the Northwestern Elevated and almost the entire extent of the Lake Street Elevated lines cross a section where the underlying formation on which the piers rest is a plastic clay.

The country on which Chicago is built is almost as level as the lake itself, and only 6 to 15 feet higher. At the level of the pier foundation, it is almost invariably saturated with water. The presence of water pipes and the slight settlement of elevated structure foundations on them have been found to contribute still further to the difficulties encountered. Where sand and gravel are found, the presence of the water does not materially affect their bearing qualities; but in the clay, failure in many cases is complete, the pier being sustained by the adjacent structure and swinging like a pendulum, distorting and tearing the plates and riveting of the structure.

In consequence of the early failure of many of the pier foundations on the Lake Street Elevated line some tests were made. The general practice seems to have been to make the base of the pier about 7 feet square, equal to 49 square feet, giving a pressure of about 20 pounds per inch. The testing appliance consists of a square wooden block or foot piece laid upon

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*Mr. Rowe has tabulated the results of his tests of paints of various brands in a statement which is on file in the Library of the Society.

the soil to be pressed, its upper surface being armed with a cast-iron plate with a socket to receive the pivot of a post on which the loading is placed; and a post provided with cross-arms and a platform to receive the loading, and a pin and guys at the top to hold it in a vertical position. The loading consists of pig iron, the pieces of which weigh as nearly as may be 80 pounds each, to facilitate the estimate of the amount of loading. The compression from the loading is taken with an engineer's level, the rod being placed on the cross-arms, and readings noted at each addition to the loading.

There were but three tests made, and these were secured only by persistency on the part of the consulting engineer.

In the first test the clay was tested at a depth of about 7 feet below street grade or 5½ feet below the original surface. The clay was in its original condition, and was a plastic yellow mass mottled with a blue or slate color, and wet to full saturation. The wooden foot plate was 18 inches square.

The following is a synopsis of the results:

Load.	Load per square inch.	Compression each loading.	Total compression.
1,500 lbs.	4.6 lbs.	0.000 ft.	0.000 ft.
3,500 "	10.8 "	0.009 "	0.009 "
5,500 "	17.0 "	0.008 "	0.017 "
7,500 "	23.1 "	0.018 "	0.035 "
9,500 "	29.3 "	0.018 "	0.053 "
11,500 "	35.5 "	0.052 "	0.105 "
12,000 failed by sliding cornerwise.			

The second test, also in clay, under similar circumstances, except that a foot piece 2 feet square was used, gave the following results:

Loading.	Load per square inch.	Compression each loading.	Total compression.
1,500 lbs.	2.6 lbs.	0.000 ft.	0.000 ft.
3,500 "	6.1 "	0.027 "	0.027 "
5,500 "	9.5 "	0.001 "	0.028 "
8,200 "	14.2 "	0.005 "	0.033 "
9,500 "	16.5 "	0.004 "	0.037 "
11,500 "	20.0 "	0.002 "	0.039 "
13,500 "	23.4 "	0.004 "	0.043 "
15,500 "	26.9 "	0.007 "	0.050 "
17,500 "	30.2 "	0.011 "	0.061 "
19,500 "	33.7 "	0.013 "	0.074 "
21,500 "	37.2 "	0.019 "	0.093 "
23,500 "	40.8 "	0.029 "	0.122 "
25,500 "	44.2 to complete failure, the block tipping slightly cornerwise as before.		

The third test on the Wabash Extension was made in the bottom of a pier foundation pit at about 1 foot below the original ground surface, the soil being an extremely fine, clean sand, the depth of which was not ascertained, but assumed to be several feet, the sand being so exceedingly fine as to be taken for clay at first sight.

The foot block used was the same as in the second test.

Loading.	Load per square inch.	Compression each loading.	Total compression.
1,500 lbs.	2.6 lbs.	0.000 ft.	0.000 ft.
7,500 "	13.0 "	0.003 "	0.003 "
9,500 "	16.5 "	0.003 "	0.006 "
11,500 "	20.0 "	0.003 "	0.009 "
13,500 "	23.4 "	0.003 "	0.012 "
15,500 "	29.9 "	0.003 "	0.015 "
17,500 "	30.2 "	0.003 "	0.018 "
19,500 "	33.7 "	0.003 "	0.021 "
21,500 "	37.2 "	0.003 "	0.024 "
23,500 "	40.8 "	0.003 "	0.027 "
25,500 "	44.2 "	0.004 "	0.031 "
27,500 "	47.8 "	0.005 "	0.036 "
29,500 "	51.2 "	0.005 "	0.041 "

It will be seen that in the first two cases the compression was accelerated at about 20 pounds to the square inch, and in the third case at about 40 pounds. In the case of the first two tests 20 pounds is the pressure at which the clay begins to flow, and may be safely called its ultimate bearing strength under a static loading. In the third test, however, the flowing could hardly have commenced at the point of acceleration, but it must have been due to a softer, less stable stratum a few feet below. Hesitancy to incur any further expense in this investigation prevented any examination of this subject.

Loading at 20 pounds per square inch is probably entirely safe in sand like that of the third test, and in sand and gravel, but on clay, with a base of the same area, there have been cases of complete failure, just as the tests indicate as probable, the column with the pier attached swinging, and being supported only by the adjacent columns, as before stated. The static load carried by each column is about 150,000 pounds, including the weight of the cars in the train, not taking into consideration the disturbing elements caused by the impact of rapidly running trains and of the tremor produced by the action of the brakes, the effect of which is difficult to estimate, but evidently of very much importance. The last two causes are the main sources of failure, as the vibrations from the structure are transmitted by means of the column to the pier and whatever movement reaches the clay upon which the pier rests very quickly affects its bearing qualities, for in its saturated state it becomes a semi-fluid very quickly. That this is due largely to impact seems apparent when it is stated that failure first manifests itself between stations where the speed is greatest. The writer thinks this kind of foundation should not be trusted beyond 10 pounds per square inch under the existing conditions, and even then the pier should be massive enough to take up the tremor largely by its inertia. If the pier is too light for this, the interposition of 2 or 3 feet of broken stone between the base of the pier and the clay might be effective and economical.

By J. A. L. Waddell, M. Am. Soc. C. E.

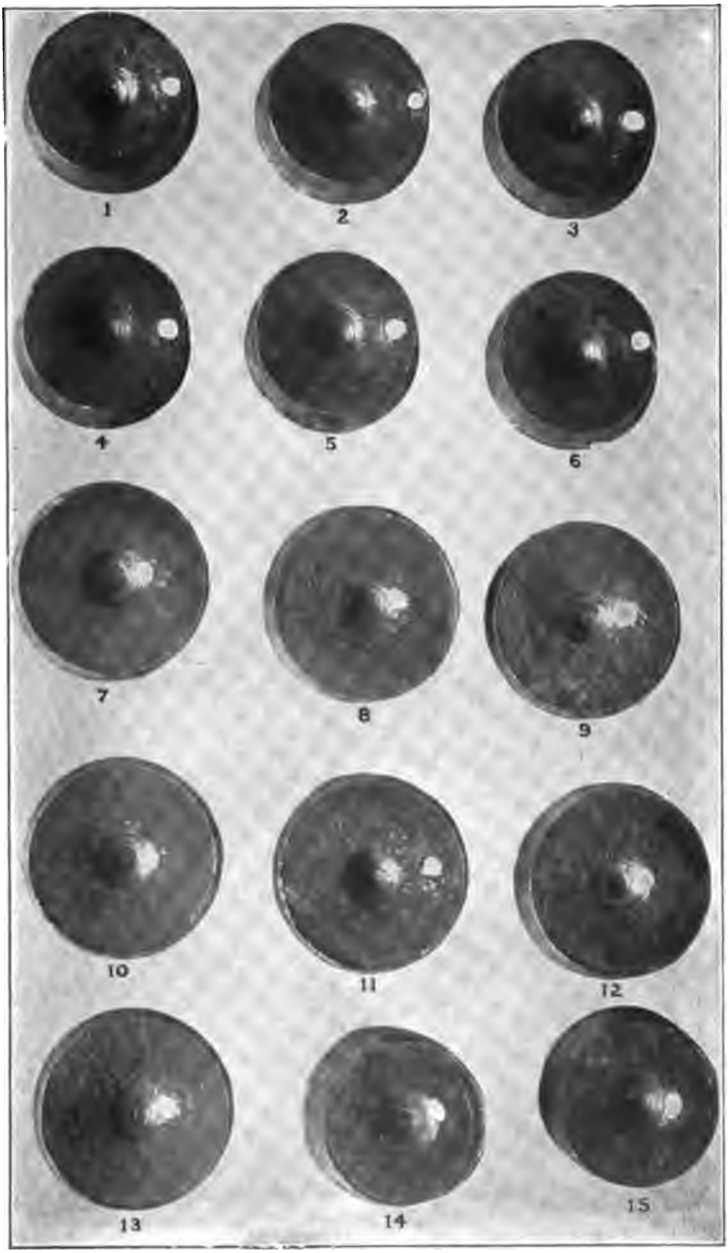
Medium Steel versus Soft Steel.—A comparison of the opinions on this subject expressed in the discussion shows quite a diversity of ideas, with the preponderance in favor of medium steel. Those who advocate the use of soft steel do so because of one or both of two claims, viz., first, when soft steel is adopted reaming may be dispensed with; and, second, soft steel is safer than medium steel on account of its greater unifromity and less liability to crack. These claims do not hold, for the reaming of every quality of steel or wrought iron is necessary, not only to remove the injured material, but also to ensure proper matching of rivet holes, and the greater uniformity of soft steel as compared with first-class medium steel is problematical. It seems from the discussions that there should be a slight difference in the ultimate strength of acid and basic steel, as suggested in the paper. Mr. Treadwell strikes the keynote to this question when he points out that the limits of soft and medium steel overlap to such an extent that manufacturers often make the same quality of metal answer for both classes, and when he suggests a compromise in the classification to suit the various manufacturers of structural steel. For such a compromise the author would suggest the following: Soft steel, 50,000 to 58,000 pounds; medium steel, 58,000 to 66,000 pounds; high steel, 66,000 to 74,000 pounds.

With this classification soft steel should be used for rivets and adjustable members only, medium steel for all other portions of all viaducts, elevated railroads, bridges of ordinary span lengths, and the floor systems and lateral systems of long-span bridges, and high steel for the main truss members and pins of long-span bridges.

It is evident that basic open-hearth steel has come to stay, and that it will be used ordinarily in preference to acid open-hearth steel on account of its slightly lower cost. It appears also that the best results are not attained with the basic product by demanding an average ultimate strength as high as 64,000 pounds; consequently, the proper thing to do is to lower the ultimate requirement to suit the manufacturers of basic steel. From the author's experience during the last three years, he would consider that a range in ultimate strength from 58,000 to 66,000 pounds would suit very well for basic open-hearth steel as at present manufactured. The soft steel, of course, would also be manufactured by the basic open-hearth process, but the high steel should preferably be made by the acid open-hearth process.

Sub-Punching and Reaming.—A comparison of the opinions on this subject expressed in the discussion shows considerable diversity, with the preponderance in favor of sub-punching and reaming. Some claim that

PLATE XI.
TRANS. AM. SOC. CIV. ENGRS.
VOL. XXXVII, No. 806.
WADDELL ON ELEVATED RAILROADS.



accurate work and properly matched rivet holes are attainable without sub-punching. Such, unfortunately, has not been the author's experience hitherto, for he has had a great deal of trouble in the field from badly matching holes whenever the sub-punching was not called for.

Anticipating claims in the discussion that rivet holes will match properly without sub-punching, the author a short time ago requested his chief inspector to procure for him from a certain prominent bridge shop, where some of his work was then being manufactured, some two dozen specimens of punching showing by the template center marks variations from correct location. Plate XI. is engraved from a natural scale photograph of fifteen of these punchings, the proper centers being indicated by the white spots, which were marked on the punchings by rubbing chalk into the template center holes.

The showing made by these specimens is most discouraging to those who hope to obtain good shop work, either by simple punching or by sub-punching and reaming. It took the inspector only about a minute apiece to find these eccentric specimens, which shows that badly matched holes at this shop are by no means uncommon, and confirms the author's opinion formed by previous experience with work from the same shop. The cause of such great eccentricity is certainly the objectionable piece-work system mentioned in Mr. Stowell's discussion. In the author's opinion, piece-work in bridge shops should be discouraged in specifications for structural steel-work. Fortunately, though, such a bad showing as that given on Plate XI. would not be made by more than one or two of the large bridge manufactories, although Mr. Horton says in his discussion that $\frac{1}{8}$-in. eccentricities in punched work are of common occurrence. The author's experience with two of the manufacturing companies on the Union Loop and Northwestern Elevated lines leads him to the conclusion that punching can be done with a general limiting variation of $\frac{1}{16}$ in. To illustrate the effects of variations of $\frac{1}{16}$ and $\frac{1}{8}$ in. for both sub-punching and full-size punching, the author has prepared the drawings shown in Fig. 38. They give the worst possible combinations of eccentric holes for two, three and four pieces of metal connected by $\frac{7}{8}$-in. rivets. It is evident from these diagrams that if the limit of $\frac{1}{16}$ in. variation be adhered to, and if the work be sub-punched and reamed, there will be no irregular holes to fill by the rivets. If the holes be punched full size, the resultant holes will often be quite irregular and probably often not completely filled. If the limit of $\frac{1}{8}$ in. variation be permitted, the reaming will make the holes nearly true circles, and small enough to be completely filled by the rivets, but when the holes are punched full size, the irregularity will often be so great that the rivets cannot fill the holes.

In the author's opinion, inspectors ought to hold down the shops to a general limit of variation in punching of $\frac{1}{16}$ in., passing occasionally a few variations between $\frac{1}{16}$ and $\frac{1}{8}$ in., and rejecting any piece where there is a variation exceeding $\frac{1}{8}$ in.

Some one may remark that, if such variations as those just mentioned be permitted, the metal injured by the process of punching will not all be removed by the reaming; but it must be remembered that it is only an occasional hole in good shop-work that will vary as much as $\frac{1}{8}$ in. from correct location, that not more than one-fourth of the holes will vary over $\frac{1}{16}$ in., and that most of the combinations of eccentricities shown in Fig. 38 will be, to say the least, unusual.

The author's experience on the Chicago elevated railroads has confirmed him, as the same experience has convinced Mr. Weston, the chief engineer, in the opinion that, except solid drilling, which as yet is too expensive, "reaming is the only method which will ensure an exact coincidence of the rivet holes in the component pieces of the various members of the structure;" and there has been nothing said in the discussion which even tends to shake the author's conviction on this subject.

Cement and Concrete.—Answering Mr. Hall's question concerning fineness, the author would state that there was no intention of excluding foreign Portland cements by specifying that 90 per cent. should pass the No. 100 sieve. In fact, there was a considerable amount of a foreign cement used at one time on the work; this was an extremely fine-ground cement and a very superior article, if not too old or damaged when used.

It has been the author's practice up to the present time to specify both superior and inferior limits for the tensile strength of cements, owing to a notion, which formerly prevailed, that a cement which develops its strength slowly is much more likely to retain it than one which develops it very quickly. The author must confess that he is still prejudiced this way, but acknowledges readily that he may be wrong in the case of Portland cements. In case of the natural cements, though, he feels confident that this notion is about right.

For field practice, the author does not specify the temperatures of the air and water, as these cannot always be regulated conveniently, but for laboratory tests he would do so.

Answering Mr. Stuart's remark about the wide latitude allowed for tensile strength, the author would reply that his specifications are so drawn as not to exclude any really good cement because of a tendency to slow setting, and, again, the results of briquette tests depend greatly upon the personal equation of the man who made the briquettes.

Answering Mr. Belknap's remark, that a one-three-six mixture of concrete will have all the voids in the stone filled, the author would reply that such would in all probability be the case, were the concrete always thoroughly mixed, but his experience proves that such a mixture often shows numerous voids. On this account, as stated in the paper, he prefers to use

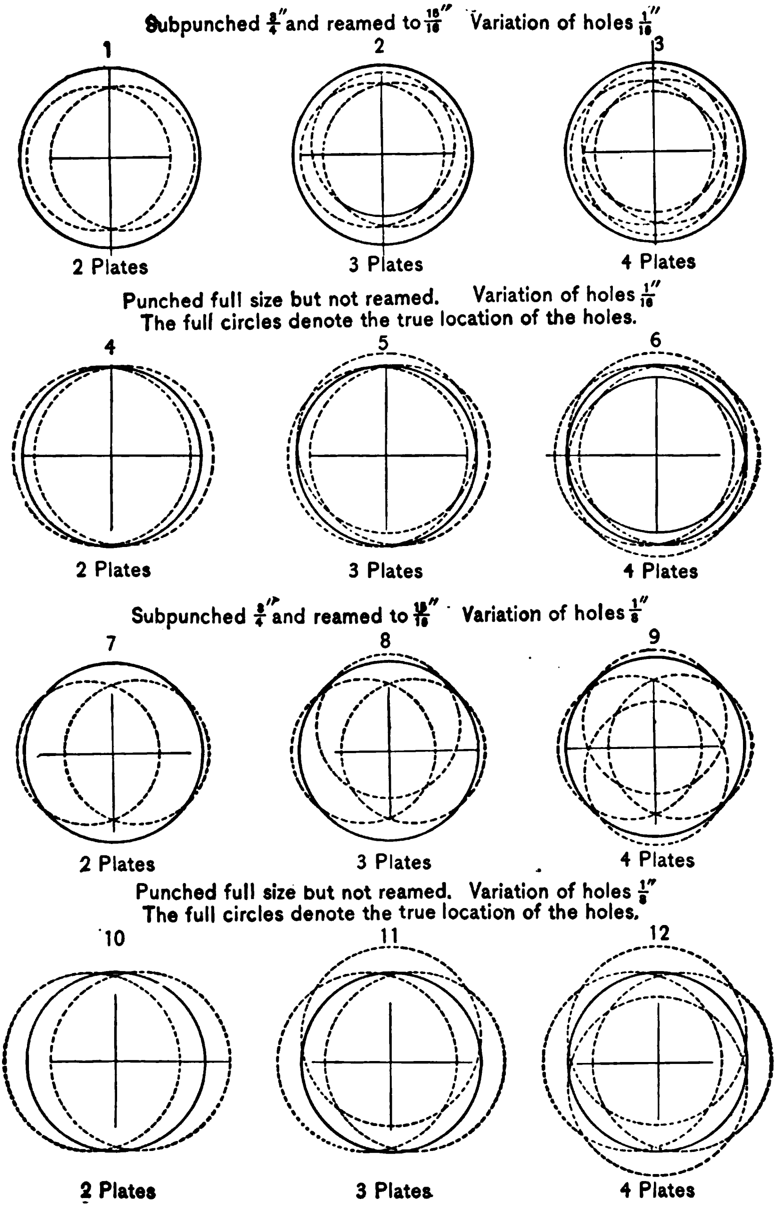

Subpunched $\frac{3}{4}''$ and reamed to $\frac{13}{16}''$ Variation of holes $\frac{1}{16}''$
1
2
3
2 Plates
3 Plates
4 Plates
Punched full size but not reamed. Variation of holes $\frac{1}{16}''$
The full circles denote the true location of the holes.
4
5
6
2 Plates
3 Plates
4 Plates
Subpunched $\frac{3}{4}''$ and reamed to $\frac{13}{16}''$ Variation of holes $\frac{1}{8}''$
7
8
9
2 Plates
3 Plates
4 Plates
Punched full size but not reamed. Variation of holes $\frac{1}{8}''$
The full circles denote the true location of the holes.
10
11
12
2 Plates
3 Plates
4 Plates

FIG. 38.

for bridge piers a one-three-five mixture for concrete deposited in the air, and a one-two-three mixture for concrete deposited under water.

The author certainly never intended to recommend an "eminently slow-setting cement" for concrete to be deposited under water. Mr. Belknap does not recognize the fact that none of the cement for the Chicago elevated railroads was to be used in that way.

Paint.—It is to be regretted that the paper has brought out so little discussion concerning the painting of metal-work. However, Mr. Rowe's investigations are valuable as far as they go, but they are unfinished.

It is often amusing to hear the conflicting opinions of even well-informed engineers concerning the paint question. Some say that the oil is everything and that any kind of a pigment will do, while others say that the pigment is the sole protective agent and the oil only a solvent. Some condemn *in toto* the use of thinners, while others say that they improve the paint and add to its life. Some say that red lead is the only proper paint to use, while others claim that it is inferior to iron oxide paints. Some think that the last-named pigments make the best possible paints, while others say that they are merely iron rust, and that their use is simply an invitation for rust to develop. Some say that patent mixtures and secret process paints are all humbug, while others pin their faith to some especial mixture or mixtures, or to some real or fancied manipulation of known or unknown ingredients. In short, the engineering profession is all at sea on the paint question, and is likely to remain there until some organized investigation is made. In the author's opinion, the subject is one of sufficient importance to warrant the appointment of a special committee of the Society to experiment and investigate on the subject for a term of several years until valid conclusions can be reached.

The author's idea of coating the metal with oil before it leaves the shelter of the roof of the rolling mill is to prevent rust from forming while the metal is in transit to the shops or while stored outside of the latter waiting to be manufactured. This method would certainly give the mill people some extra trouble, but that could be paid for. It is claimed, and perhaps justly, that the greasy surface of the oiled metal gives trouble in laying off the work in the shops, and that on this account a coat of carbon primer at the mills is preferable.

The author's preference for Eureka paint was due primarily to the high recommendation given it by Mr. A. P. Boller, M. Am. Soc. C. E., which was confirmed later by the results of Mr. Rowe's preliminary experiments. Mr. Rowe found, however, several other paints that stood his tests as well as did the Eureka.

One objection to a coat of oil alone at the shops after manufacture is that when the metal is shipped there is often no certainty as to how soon it will receive its first coat of paint. The author has often noticed metal-work badly rusted because it was only oiled at the shops and because its erection was delayed. The shipping of metal-work covered with undried paint, as mentioned by Mr. Boller, is a very reprehensible practice and should be prohibited in standard specifications for structural metal-work.

The great uncertainty on the paint question is due to a number of causes, the principal of which are the following:

Permitting rust to form on the metal before the first coat of paint is applied.

Applying the first coat improperly, covering metal from which mud, ice, grease, etc., have not been removed.

Adopting cheap paints from false notions of economy.

Dishonest practices on the part of the manufacturer or mixer of the paint.

Carelessness in mixing paint and neglecting to keep heavy paints properly stirred.

Slovenliness in applying the paint to the metal.

Using paint that has stood in pots over night and has deteriorated in consequence.

Neglecting too long to repaint and thus allowing rusting to set in.

The requisites for an ideal metal paint are the following:

Thinness, so that it can be applied readily, and so that it will cover a comparatively large surface per gallon.

Lightness of the solid particles, so that there will be no settlement in the bottom of the paint pot.

Great and close adhesiveness to the metal.

Quickness in drying.

Absence of blisters in both fresh and old painted surfaces.

Ability to receive well and retain closely one or more additional coats of paints of the same kind or of other kinds.

Durability.

Cheapness in first cost.

The man who will invent a paint that will fill all eight of these requirements, and who can demonstrate to engineers that he has done so, can certainly make a fortune out of his invention.

Four-Column versus Two-Column Structures.—Several engineers appear to disagree with the author in his preference for the four-column structure. He was influenced in his decision principally by the following reasons:

The cantilevering of an entire track beyond a column is rather awkward construction and causes reversing stresses in the cross girder.

The thrust from braked trains can be more readily taken care of with four columns than it can with two.

The four-column structure will prove more rigid than the two-column structure.

Mr. Pratt's objection to the four-column structure on account of the possibility of the settlement of foundations is not a valid one, for properly designed and built foundations will never settle. If a single settlement of a pedestal on either of the author's Chicago lines of elevated railroad ever occurs, it will be a matter of great surprise to him, although he is not responsible for the sizes of the concrete pedestals, as Mr. Weston varied them to suit the different conditions as they developed. However, Mr. Weston has always tried to err upon the side of safety on this question of foundations, owing to the expensive experience he has had in repairing the faulty work on the old portion of the Lake Street Elevated, which was built before he was chief engineer.

Mr. Pratt's unfortunate experience with pedestal foundations may be due to a softer stratum of material underlying the gravel, or perhaps to the fact that it is within the realms of possibility to double the pressure on one side of a pedestal foundation by the thrust of a braked train.

As the author has designed the metal-work on the Northwestern Elevated, a settlement of one pedestal in a bent would be less injurious to it in the case of the four-column structure than it would be in the case of the two-column structure.

Mr. Gates' objection to the four-column structure because of obstruction to traffic will not hold, as this class of construction is used only on the company's private property, where no traffic exists.

Braced Towers versus Solitary Columns.—The author's braced tower design appears to have met with general approval from those discussing the paper, although Mr. Smith dissents from it, stating that the thrust from braked trains "is not conveyed, to any extent, to the columns," and that "no bending can be produced upon the columns, for it is counteracted by the deck."

These statements are certainly incorrect, for no one will deny that there is a great thrust exerted by stopping in the shortest possible distance, with the air brakes, a train moving at a velocity of 40 miles per hour, and that this thrust must eventually reach the ground. If there be longitudinal sway bracing like that adopted for the Northwestern Elevated, the thrust will travel by that; but, if not, it must go by way of the columns and produce bending thereon.

It is true that the continuity of the deck tends to distribute this thrust over a number of columns, but the extent to which this distribution takes place is a matter of surmise. Some engineers appear to forget that when a light column carrying a vertical load is deflected from the vertical by a thrust, it is subjected to two bending moments, viz., that due to the thrust itself and that due to the vertical load, the lever arm for which is the total deflection. The column has therefore to withstand the combination of these two moments and the vertical load. Mr. Smith says that the thrust upon one track is distributed over the other three. He forgets that two trains on contiguous tracks will often approach a station at the same instant, running in the same direction, with the brakes set. If at the same time there be a train or two trains starting on the other tracks, all three or four thrusts will be in the same direction. Mr. Smith talks of setting the structure in motion before any bending of columns can occur. He would reduce the question to one of dynamics, while it is, upon the face of it, simply one of statics. He says:

> "Were it possible to design a column section in any case which would carry the load due to compression without longitudinal strength, then some metal might, in this case, be necessary to withstand any light stress caused by the thrust. This being impossible, however, the conclusion is drawn that any metal used in any part of a structure to withstand horizontal thrust in a longitudinal direction is superfluous and needless expense."

This is a bold statement by Mr. Smith, and probably he is the first to express it so plainly, although some such erroneous notion must have existed in the minds of the designers of most of the older elevated railroads.

Mr. Campbell's experience on the Sioux City Elevated, where the effects of both longitudinal and transverse thrusts on the columns were entirely ignored, is pretty conclusive as to the necessity of giving due consideration to horizontal loads. As Mr. Campbell states, the vibration of the structure "was plainly noticeable at a point 2,000 ft. away from the moving train." The author has been told that during erection long portions of this structure moved as much as 2 ins. longitudinally and had to be moved back by jack-screws. In this work the columns were proportioned for the effects of live and dead loads only, as Mr. Smith would advise.

To illustrate the necessity for taking care of longitudinal thrust and traction of trains, the author herewith reproduces extracts from a letter concerning the paper from Mr. H. G. Kelley, M. Am. Soc. C. E.

> "Many of the points involved are of special importance, and if accepted as correct will require a radical departure on certain lines from the present methods of design.
>
> "The point to which my attention has been especially directed by reading your paper is the resultant of the traction force exerted by engines, and the effect of such resultant upon structures, due to the passage of engines and trains. The mathematical principles involved will no doubt be brought forth in the published discussions, and while your assumption that 20 per cent. of the greatest live load between two adjacent expansion points will act as a horizontal thrust may not be entirely agreed to, nevertheless experience has shown that a considerable allowance should be made

and provided for; therefore any facts obtained by actual experience in construction and maintenance will assist materially in arriving at a true conclusion, and in this consideration wooden trestle-work, which constitutes a large portion of the bridging of this country, should not be excluded, for it presents valuable information concerning structures in which theoretical considerations are usually excluded, and details to take up or reduce longitudinal vibrations are seldom constructed.

"I will therefore present one case coming under my own observation, and in fact under my charge, which is an especially valuable one, showing, as it does, that a longitudinal vibration is transmitted through elevated structures for surprising distances. The structure is a wooden trestle, upon the line of the St. Louis Southwestern Railway. This trestle was constructed of pile bents, with panels of 13 ft. 8 ins.; each bent contained four piles, except in the deepest portions, where five piles were used to the bent; the piling was of oak and red cypress, with specifications calling for not less than 10 ins. of heart at the point; the deck was composed as follows:

"Caps........	12 x 12 ins.,	12 ft.	long.
"Stringers....	6 x 14 "	14 "	long, 3 ply on each side.
"Ties.........	6 x 8 "	9 "	long, with 12 ties to the panel.
"Guard rails..	6 x 8 "	16 "	long, notched down 1 in. over the ties, and bolted to every fourth tie.

"Every cap was drift-bolted to each pile under it, and each chord of stringers was drift-bolted to the caps.

"Upon examination of the drawing (Fig. 39), which I enclose, you will note that the trestle varies from 10 to 30 ft. in height, and has a total unbroken length of 9,338 ft., with three curves in its length.

"Upon assuming charge of the bridge department of the above-mentioned road several years ago, it became necessary to make a personal examination of the various structures, and I have selected the case of trestle 492 as one out of several trestles of unusual length where the same results were noticed. My first inspection of this trestle showed a visible longitudinal variation of such extent, under the passage of trains, that a careful investigation was made to determine the extent and force of the thrust.

"To make the following facts perfectly clear, reference should be made to the accompanying drawing (Fig. 39). From this you will notice that at its north end the trestle connects with a bridge across the White River. This bridge at the time of the observation consisted of an iron draw span of 355 ft., and two combination Pratt trusses of 125 ft. each, one span being at each end of the draw span; both of these combination spans were upon falsework. The observations disclosed that, when any north-bound train, even at a speed of but 12 miles an hour, rolled upon the trestle at its extreme south end, a longitudinal vibration was transmitted in a few seconds to the north end of the trestle, and by the time the train would reach the tangent, at station 902, the vibration at the span reached a maximum of 1½ ins., this impulse being conducted to the span itself and vibrating it in unison with the trestle, the measurements being taken at the point where the rails of the fixed span rested upon the end floor beam rail rests of the draw span. The construction of the trestle precluded the opinion that the vibration was confined to the deck alone, for the drift bolting to the caps made it certain that a portion of the thrust was communicated through the piling to the ground, causing the piling to act as beams as well as posts.

"I at once had constructed a system of struts to take up or reduce the thrust, the general plan of which is shown on the drawing (Fig. 39). It consisted of two yellow pine beams, 10 x 12 ins. in cross-section, running from the cap on one bent to a brace timber at the foot of the piling on the second bent each way from the first one; and in addition to this, iron tension rods, 1⅜ ins. in diameter, were placed beside each strut and brought into tension with turnbuckles.

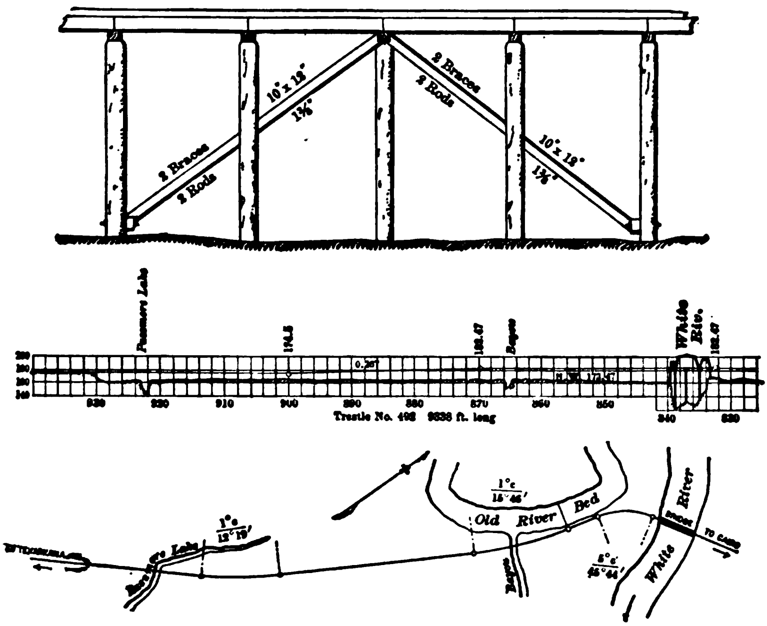


FIG. 39.

"This system of strutting was constructed at two points in the trestle, and practically takes up all vibrations, but under the influence of a heavy freight train I have seen these strut timbers buckle from ¼ to ⅜ in. out of line in the direction of their least dimension.

"The necessity for this strutting has become so apparent that I provide for it on other important trestles of extreme length by using a modification of the original plan."

Had Mr. Kelley tried the experiment of bringing the train to rest suddenly on the trestle with the air brakes, he might have found a vibration even greater than the 1½ ins. observed, although this is large enough. Mr. Kelley's remarks about the buckling of his longitudinal timber struts from the longitudinal thrusts of heavy trains ought to be sufficient to convince even the most skeptical that such thrusts do exist and that they are carried down to the ground by the columns.

Mr. Parsons' transit observations on one of the New York elevated railroads gives additional evidence of the effects of thrust from braked trains.

How any one can deny that large vibrations are injurious to metalwork it is difficult to conceive; for, as before stated, they put a double bending moment on the columns, and tend to work loose the rivets that connect the deck thereto.

Mr. Nichols and two or three other engineers question the author's assumption of 20 per cent. as the co-efficient of friction for the thrust of a braked train. Troutwine places it as high as 25 per cent., while Messrs. Cooper, Schneider and other writers of standard specifications make it 20 per cent. As for the distribution of the thrust, the rails and guards on tangents certainly tend to distribute it over some distance, especially when the track is new; but, on sharp curves and with old track, it would not be proper to place much reliance upon such distribution. Moreover, why divide up the thrust, when assuming it concentrated produces such beneficial results to the whole structure by increasing its rigidity? When the columns are fixed at both top and bottom, as is the case on all of the author's Chicago work, the lever arm of the thrust is only one-half of the unsupported length of the column, consequently the bending moment and the section of column required to withstand it are by no means excessive. This is shown by the comparatively small weights of metal in the author's designs, viz., 391 pounds per lineal foot per track for a four-track structure on private property, 385 pounds per foot per track for a double-track structure on same, 485 pounds per foot per track for a double-track structure spanning a double-track cable railway in streets, and 571 pounds per foot per track for a double-track structure in streets spanning from curb to curb with 41 ft. between centers of columns. It is true that these figures are for the comparatively light live load assumed for the Northwestern Elevated, but the assumption of a heavier live load would affect little else than the sections of flanges of longitudinal girders, and in street lines those of cross girders also.

From the tables in Mr. Nichols' paper* entitled "The Brooklyn Elevated Railway," the author has compiled the following weights of metal per lineal foot of double-track structure, omitting the weights of station metal and not considering the "Old Brooklyn Line." For columns on curbs the weights run from 1,095 pounds for a 32-ft. spacing up to 1,469 pounds for a 45½-ft. spacing, and for columns in the street 1,195 pounds. The corresponding weights for the Chicago Union Loop are 1,375 pounds

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* Proceedings Institution of Civil Engineers, Vol. cxxvii, p. 333.

for a spacing of 41 ft., and 1,150 pounds for columns in the street. If an interpolation for a 41-ft. spacing is made in Mr. Nichols' weights, 1,344 pounds will be found; and, averaging this with the weight of structure for columns in street, 1,270 pounds is obtained, as against 1,263 pounds, the corresponding average for the Union Loop, showing that the author's Chicago structure is a little lighter than the average for corresponding lines in Brooklyn, in spite of the fact that the author's live load is on an average for all parts of the structure 17½ per cent. greater than that used in designing the Brooklyn lines, as indicated in Mr. Nichols' paper. With such a showing as this, the author cannot be justly accused of extravagance in his designs because he proportioned his columns for the effects of thrust from braked trains and endeavored throughout his entire designs to conform in every particular with the principles of design enumerated in his paper.

If anyone doubts the advantages of putting a little extra metal into the columns and fixing them at both top and bottom, let him stand for a while on one of the platforms of the Union Elevated Loop of Chicago and note the vibration, then try the same experiment on a number of the elevated railroads of New York and Brooklyn, and compare the results. He would probably be considerably surprised; for he would find hardly a tremor on the Chicago road, while on some of the Eastern roads the vibration would be so great as almost to prevent him from writing legibly in a note-book.

Wooden Floor.—Replying to the comments of Mr. Nichols and others on the wooden floor system adopted, the author would state that it was based upon the results of the experience of those who have been operating elevated railroads for many years. Whether both inner and outer guards are requisite is certainly problematical. In railroad bridges the author relies on the inner guards to keep derailed wheels from receding far from the rails, and on the outer guards to space the ties and keep them from bunching.

Mr. Weston has made two or three improvements on the original design for the floor system, notably the use of tie-plates.

Replying to Mr. Stuart's remark concerning the use of short hook bolts, they were necessitated by the 5-ft. spacing of the longitudinal girders.

Mr. Pegram's design for a floor without cross-ties, as adopted for the Kansas City Elevated Railroad, has one very serious fault, viz., that the trough will collect snow and sleet, which in a cold climate would be liable to freeze to such an extent as to stop traffic altogether.

The author cannot agree with Mr. Tomlinson's view that an 18-in. spacing for 6 x 8-in. ties is an improvement on a 14-in. spacing, for the reason that a derailed wheel has a pretty deep hole to drop into when the open space between ties is 10 ins. wide, and that the bumping which would result from climbing over the ties and dropping between them would be liable to cause disaster. Fig. 40 shows relative conditions that would exist with a 30-in. derailed wheel, assuming that the flanges cut into the ties ½ in. at the corners.

Answering Mr. Belknap's charge expressed thus, "it is difficult to conceive that a railroad company would countenance the gross extravagance of using the most costly grade of timber when the preservative treatment of cheaper grades would give an article much more economical," the author would reply that, in asking for bids on timber, two specifications were used, the first being the author's calling for clear heart timber, and the second that of the Manhattan Elevated Railroad Company allowing a certain amount of sap wood on the corners. The difference in the lowest bid on the two specifications amounted to about 50 cents per thousand, so the president of the railroad company himself decided to adopt the heart timber. In spite of what Mr. Tomlinson says to the contrary, the author thinks that this was a wise decision, for it is the sap wood, both treated and untreated, that fails first.

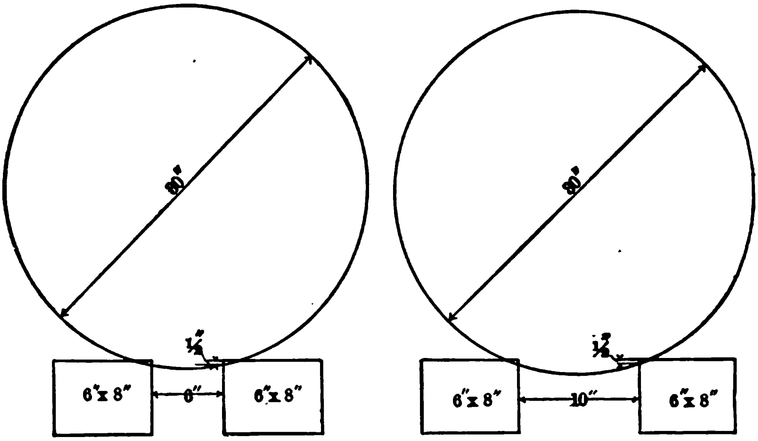


FIG. 40.

Data Concerning Existing Elevated Railroads.—It is possible that the author has, much to his regret, given offense to certain engineers by his sweeping assertion that "the results of his investigation, as far as the designing of the metal-work is concerned, amount simply to the accumulation of a great mass of information exemplifying 'how not to do it.'" Such was certainly not his intention, although the statement was made with due intent and to accomplish an important object. Moreover, later and more extended examinations of existing structures confirm him in his opinion.

The *raison d'être* for his statement is that, when both the Wabash Avenue Extension of the Lake Street Elevated and the Northwestern

Elevated contracts were about to be let, the strongest kind of pressure was brought to bear upon the president of these companies to induce him to set aside the author's plans and specifications and to adopt others submitted by bidders on the plea that the latter were the same as those used for the New York and Brooklyn elevated railroads, which roads represented practically the *ne plus ultra* of both design and manufacture. It was with great difficulty that the author overcame this opposition; but, thanks to the sound business policy of the president, he was finally successful in having both his plans and his specifications adopted and adhered to. Were it not for this stand which he then took, the unscientifically designed and crudely manufactured structures of the New York and Brooklyn elevated railroads would still be the criterion of excellence for that class of construction, notwithstanding the fact that the Metropolitan Elevated of Chicago, then in course of construction, is in most particulars greatly their superior.

The true reason why elevated railroads have been so unscientifically designed in the past is that, as a rule, the designing has been left almost exclusively to the manufacturing companies, which being more interested in profits than in anything else, naturally detailed the metal-work so as to have it go through the shops quickly and erect readily; and all considerations of scientific design appear to have been ignored because of these requirements.

The intent, therefore, of the author's "sweeping assertion" is to establish for all future elevated-railroad work a precedent for taking the designing and the preparation of the specifications entirely out of the hands of the manufacturer of structural metal-work and placing them where they belong, viz., in the hands of the consulting engineer and expert in such construction. Whether the attempt will prove successful remains to be seen.

Thanks to the courtesy of Mr. Clarke, in forwarding an advance copy of his discussion, the author was convinced of the necessity of having a thorough examination of all the New York and Brooklyn elevated railroads made by a competent engineer, in order to enable him to answer properly, not only Mr. Clarke's discussion, but also those of like tenor, the writers of which take exception to the author's "sweeping assertion." It was therefore decided that the author's chief office assistant, Mr. Ira G. Hedrick, Assoc. M. Am. Soc. C. E., should proceed East to make the necessary examination and report. Following are extracts from his letter of instructions:

"You will please proceed to New York at your earliest convenience and examine thoroughly all the elevated railroads of both New York and Brooklyn, with a view to ascertaining whether they show any signs of incipient failure, and, if so, what such failures consist of and the causes thereof. After your examination is finished, you will please make me a full and elaborate report of the results of your investigations. In this report I desire you to point out all departures in detailing from the requirements of good construction as outlined in my paper on elevated railroads, and indicate the evil effects of such departures, if there be any. You will, when in New York, call on the Secretary of the American Society of Civil Engineers and obtain from him copies of all the discussions of my paper, so as to include in your investigations a study of all points concerning existing elevated railroads that are raised in the said discussions. In reporting to me you will please answer all such points, so that I can incorporate your report in my *résumé*, and thus let you reply for me to the statements made in the discussions."

In accordance with these instructions Mr. Hedrick spent some two weeks in New York and Brooklyn making his investigations, and after his return presented a report from which the following extracts are made:

"Referring to the discussion of Mr. O. F. Nichols, M. Am. Soc. C. E., the writer is of the opinion that in most instances in the New York and Brooklyn lines the connections of columns to foundations are strong enough to take care of all stresses that ever come upon them. Plenty of anchor bolts are used, and these are carried well down into the foundations, and the cast-iron bases grip the feet of columns firmly, so long as the cement or filling used between the column and casting is well preserved. Where columns are placed in the roadway, cast-iron bases, such as are used for the Second Avenue line in New York, or for the Kings County Elevated in Brooklyn, are probably as satisfactory and economical as any that can be used. But where columns are on curbs, or on private property, the column foot shown on Fig. 5, which was used on the Northwestern Elevated Railway, is equally as good and certainly much more economical."

"Where the bases are made of structural steel, no lugs are used on the columns, but the anchor bolts merely pass through the base plate and angles connecting the column to the base plate. Four anchor bolts are used for each column, and they are placed very near the corners of the base plates; therefore the strength and rigidity of the connection between the column and the pedestal depend entirely on the ability of the corners of the base plate and angle to resist bending. This style of base is certainly not so strong as where the anchor bolts pass through bent plate lugs which are firmly riveted to the feet of columns, as is done in the detail used for column bases on the Northwestern and Union Loop Elevated Railways in Chicago.

"In regard to the actual amount of longitudinal thrust load from braked trains, and the distribution of this load over the structure, there seems to be considerable difference in opinion among engineers, and Mr. Nichols takes a very decided stand against the assumptions used in designing the Northwestern and Union Loop Elevated Railways.

"While it is no doubt true that the assumption that 20 per cent. of the greatest live load between two expansion joints acts as a horizontal thrust upon the columns between same is on the side of safety, yet it is a fact that light columns and weak connections between columns and cross girders are probably the causes of more vibration in the existing elevated structures in New York and Brooklyn than are all the other objectionable features combined. On all of these structures, excepting in one or two instances, a very perceptible longitudinal vibration can be felt when the brakes are applied to a train, and in the taller portions of the Second and Eighth Avenue lines these vibrations seem to have an amplitude of from one-half inch to an inch.

"On most of these lines there is an expansion joint in each panel, which arrangement makes each bent act alone in resisting the longitudinal thrust that may come upon the panel attached thereto, excepting, of course, the aid it may receive through the track system.

"The writer cannot agree with Mr. Nichols in regard to the continuity of track and the consequent distribution of this horizontal thrust or traction load, as all joints in the track rails and guard timbers must adjust themselves for expansion and contraction of the metal superstructure, and consequently the whole structure is practically non-continuous over expansion joints; therefore the most scientific and rational way to design the columns and cross-girders is to proportion them so that each section of structure between expansion joints can take care of itself entirely independent of any other part of the structure.

"On the portion of the Suburban Rapid Transit Line which rests on brick piers there is, as stated by Mr. Nichols, absolutely no vibration, although the longitudinal girder construction is similar to that of other portions of the structure which are supported on steel columns and in which there is considerable vibration, yet not so much as in many of the older lines. This structure on brick piers certainly demonstrates the truth of your column theory in a most impressive way, and shows conclusively that the great cause of vibration in ordinary construction lies in the columns and their details, and the writer is therefore convinced by his observations that metal, properly applied, is never wasted in columns, although the sections may seem heavy.

"On none of the elevated railways in New York and Brooklyn is any attempt made to carry the longitudinal thrust directly into the columns by lateral struts, and consequently there is considerable cross bending on the transverse girders where the columns are placed on the curbs and where the tracks are located near the center of the streets. But this bending does not affect the structure so much where the cross girders are double and where the columns are in the street and the tracks placed over them. The bad effects of this bending are noticeable on some of the down-town lines, in which there is a slight canting of the cross girders when the brakes are applied to passing trains, and in some cases the bolts attaching the longitudinal girders to cross girders have to be frequently replaced.

"By extending the lateral bracing out to columns and thus firmly fixing their tops, as is done on the Union Loop Elevated Railway in Chicago, the bending on cross girders is entirely avoided and a much more rigid construction is secured, which can best be appreciated by standing on the last-named structure while the brakes are applied to trains. The writer regrets that he could not take vibration curves on the various structures he inspected so as to give a more definite idea of their relative rigidities, and thus prove conclusively the superiority of the well-braced structure.

"The writer agrees with Mr. Nichols in regard to the spacing of expansion pockets, and the greater rigidity of the structures in which they are spaced from 150 to 250 ft. apart is very noticeable. The limiting distance for spacing expansion pockets depends upon the stresses produced in columns by the expansion and contraction of longitudinal girders due to changes in temperature. The more rigid the columns, the greater will be the temperature stress for any given distance between expansion pockets, and *vice versa.* For the Union Loop the limiting distance was found to be 150 ft., but on the Suburban Rapid Transit Line, with expansion pockets 250 ft. apart, the metal in columns is probably not strained any higher by temperature stresses than that in Union Loop columns, on account of the much less rigid column section used on the Suburban Rapid Transit line.

"In regard to column sections, there is certainly a great diversity of opinion among engineers, as is evident from the many different styles used on the lines in New York and Brooklyn, and it is certainly a difficult task to design a column which is satisfactory in every respect. The Phœnix column and a column made of two channels laced together are used on the New York and Brooklyn elevated roads more than any of the other styles. There are objections to both of these columns. The Phœnix column is inaccessible for paint on the inside, and consequently its interior is subjected to the unmolested ravages of rust. It may be claimed that no moisture can get inside the column, and therefore that there is no necessity for the application of paint; but that an abundance of moisture and water finds its way to the inside of these columns is proved by the fact that during the winter season these columns are often burst open by the freezing of the accumulated moisture inside. The possible occurrence of such a result makes another serious objection to the Phœnix column.

"The two-channel column with double-riveted lacing is certainly the most satisfactory column used on any of the elevated railways in New York or Brooklyn, but in most instances its efficiency is largely destroyed by cutting the column off below the bottom of the cross-girder. The Fifth Avenue line in Brooklyn and the Third Avenue line in New York furnish examples of this defective style of construction, and will be considered later on in this report. The columns built of two channels laced together usually have the webs of channels placed parallel to the center line of structure, so that the webs of channels carry the shear from longitudinal thrust, and the lacing carries the shear from transverse loads. The double-riveted lacing is surely ample to carry the transverse loads due to wind, but on curves the centrifugal load could be much more satisfactorily carried by solid webs, as there is in all cases considerable vibration from trains passing around curves. Two 15-in. channels with webs turned parallel to center line of structure do not give nearly as strong a section longitudinally as two channels and one I-beam, the section used on the Union Loop of Chicago. This I-beam column is just as satisfactory, as far as proper connections are concerned, as the two channel column, and is certainly much more rigid in both transverse and longitudinal planes.

"The investigations made by the writer verify your assertion that all columns should be extended up to tops of cross-girders, which should be solidly riveted into them.

"The assertion by Mr. Nichols that the later structures in New York have the tops of columns so firmly fixed that the structures could be slid bodily over the ice without the columns collapsing would, in the writer's opinion, apply only to the Suburban Rapid Transit Line in New York.

"The straight brackets in use on most of the lines in New York and Brooklyn consist of two small angles with two and three rivet connections to cross girders and columns, and are almost absolutely useless as bracing. The rivets in these connections work loose, showing that the details are weak and overstrained. A straight bracket with a solid web would be more efficient than a curved bracket, but less pleasing in appearance, but the curved bracket with a solid web is incomparably better than the angle brackets in such common use on the older lines.

"Referring to the discussion by Mr. T. C. Clarke, M. Am. Soc. C. E., the writer made a careful examination of the Second Avenue line in New York, and in the following pages each of the seventeen essentials of good construction given in your paper are applied to the above-named structure and the evil effects of the violation of these essentials are pointed out.

"1. *Insufficiency of Rivets for Connecting Diagonals to Chords of Open-Webbed Girders.*—The diagonals in the longitudinal girders of the Second Avenue line are each composed of two angles varying in size from 6 x 4 ins. at ends to 4 x 3 ins. at center. The diagonals are of the single-intersection Warren girder type, and in no case do they intersect on center-of-gravity lines. There are only four or five rivets connecting these diagonals to the chords, and as there are no connection plates in the girders, the rivets connecting the diagonals to the chords are bunched in such a small space that it is hardly probable that the full value of these few rivets is obtained. Some of these rivets are working loose, but not so many as would be expected. Judging from the investigations made, there is probably, on the Second Avenue line, an average of about twenty loose rivets per mile per month in the diagonals of longitudinal girders. This number is only about one-third as many as are found on the Third Avenue line, but certainly many more than should be found on a structure which has been properly designed.

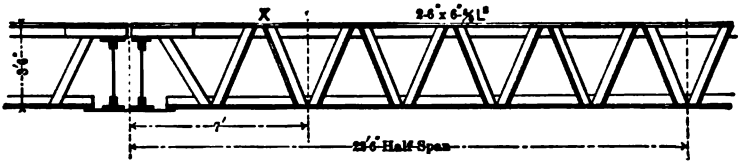


FIG. 41.

"2. *Failure to Intersect Diagonals and Chords of Open-Webbed Girders on Gravity Lines.*—In none of the longitudinal or transverse girders of the Second Avenue Line do the diagonals intersect on gravity lines, while near the ends of these girders where large angles are used these diagonals intersect in some cases as much as 8 in. off centers.

"It will be interesting to take the case of a 45-ft. span (Fig. 41) and figure the combined direct and bending stress on the top chord. The loads assumed for these calculations are the same as were used in designing the Union Loop.

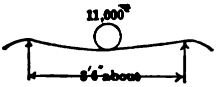
Dead load per lineal foot of track.. 700 lbs.
Live load " " " .. 2,500 "

Total load " " " .. 3,200 lbs., or, 1,600 lbs. per lineal foot per stringer.

"Moment at center of girder $= \frac{1}{8} \times 1{,}600 \times (45)^2 = 405{,}000$ foot-pounds. Effective depth of girder = 3.25 ft. Stress $= \frac{405{,}000}{3.25} = 124{,}600$ lbs.

"Bending on top chord. Let us use the compromise formula $M = 0.1\ Wl$.

Live load, $M = 0.1 \times 11{,}000 \times 42 = 46{,}200$ inch-pounds.



Dead load $M = \frac{1}{12} \times 350 \times 35 \times 42 = 4{,}290$ inch-pounds.
Total bending moment $= 50{,}490$ "
Section for top chord, assumed, two 6 x 6-in. 72-lb. angles.
Moment of inertia of top chord = 45 net.

$$R = \frac{4.25 \times 50{,}490}{45} = 4{,}768 \text{ lbs.}$$

$$\text{Direct stress} = \frac{124{,}600}{14.4} = 8{,}653 \text{ lbs.}$$

"Total extreme fiber stress in center panel of top chord due to combined direct load and bending = 13,421 lbs. per square inch. This is too high an intensity to use where the loads are so frequently applied as they are on this line. The intensity used for the top chord sections on the Union Loop was 9,000 lbs.

"Let us try the end detail of these longitudinal girders. End shear $= 22.5 \times 1{,}600 = 36{,}000$ lbs.; eccentricity = 12 ins.; moment due to eccentricity $= 36{,}000 \times 12 = 432{,}000$ inch-pounds; moment of inertia of section on *A B* (Fig. 42) = 160 net; $R = \frac{3.5 \times 432{,}000}{160} = 9{,}450$ lbs., which is all right.

"Let us try an intermediate panel point "X," Figs. 41 and 43. Direct stress in second panel of top chord $= \frac{36{,}000 \times 7}{3.25} = 77{,}540$ lbs. Therefore $P = \frac{77{,}540}{14.4} = 5{,}385$ lbs.

$P = 5{,}385$ lbs.
Bending from wheels
$R = 4{,}768$ "
Bending due to eccentricity $R = 11{,}787$ "
Total extreme fibre stress = 21,940 "

Stress in diagonal = 15,600 lbs.
Lever arm for eccentricity = 8 ins.
Moment $= 8 \times 15{,}600 = 124{,}800$ inch-pounds.

$$R = \frac{4.25 \times 124{,}800}{45} = 11{,}787 \text{ lbs.}$$

"This is too high to strain the top flanges of these girders. From the above figures it will be seen that the eccentric connections are the cause of more stress in the top chords than the combined direct load and bending due to wheel loads. Such unnecessary stresses should certainly not exist in a well-designed structure.

"4. *Failure to Proportion Top Chords of Open-Webbed Longitudinal Girders to Resist Bending from Wheel Loads in Addition to Their Direct Compressive Stresses.*—From the figures made for section 2, it will be seen that the stresses in top chord angles are not excessive for the combined direct load and bending due to wheel loads on top chords, but that the stress due to eccentric connections combined with the two cases named above increases the total intensity to about 100 per cent. above what it should be. With proper connections the top chords of this structure would not be overstrained more than 45 per cent.

"5. *Insufficient Bracing on Curves.*—On the Second Avenue line no bracing is provided on curves, except the ordinary stringer bracing. As a result of this neglect, the stringer bracing connections on curves are badly overstrained, and the rivets are continually working loose. The bracing frames between adjacent stringers seem to suffer especially from the centrifugal load, and as the diagonals in these frames are of small flat bars, connected by one rivet at each end, and at the intersection at center, they are entirely inadequate for the work they have to do. There is great vibration on all curves caused by passing trains, although their speed is much reduced as they approach the curves.

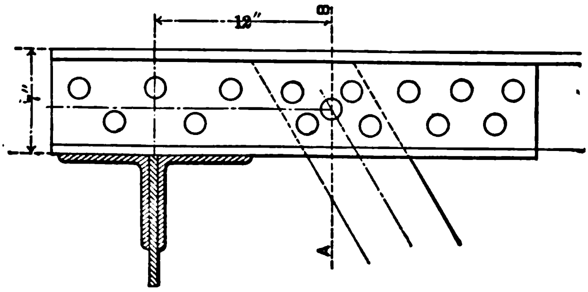


FIG. 42.

"On Twenty-third Street, where the line runs from First Avenue to Second Avenue, there is a short tangent between two very sharp curves, and the lack of sufficient bracing is clearly shown by the swaying of the structure in both transverse and longitudinal directions as the trains pass around these curves.

"Rigid bracing frames placed at center of panels would add greatly to the rigidity of the structure. A comparison of the action of this structure with that of the Union Loop Elevated in Chicago under similar loads and conditions would show the great advantage to be derived from a rigid lateral system on curves.

"6. *Insufficient Bracing between Adjacent Longitudinal Girders.*—On the entire Second Avenue line the adjacent longitudinal girders are braced together with 3 x 3-in. angles in the planes of both top and bottom flanges, with a bracing frame at each end of panel, and one or more at intermediate points according to length of span. As stated before, the diagonals in the bracing frames are of small flats and of very little value as bracing. The bracing angles between the adjacent longitudinal girders are ample to carry all stresses which can come upon them where the structure is on tangent, but as no plates are used for connecting these angles to the longitudinal girders, only two rivets are used to attach them to the girders. These two-rivet connections do not stand the wear and tear of the constant vibration produced by the heavy traffic, and as a result many of these rivets work loose. The single rivets in the bracing frame connections also frequently work loose. Enough metal has been used in the bracing between longitudinal girders to make a thoroughly rigid system if properly distributed. If the bracing angles between bottom flanges of girders had been omitted and the same amount of metal had been used in providing suitable connection plates and rigid bracing frames joining the longitudinal girders at the center of panel, and if all connections had been made with three or more rivets, the structure would be more rigid and there would be no trouble with loose rivets in the lateral bracing.

"8. *Excess of Expansion Joints.*—In the Second Avenue structure, provision is made for expansion in every panel, and this excess of expansion joints is one great cause for vibration in the structure. Neglecting the continuity of the track, each bent has to take care of all longitudinal thrust from traction or braked trains coming on the panel which is attached to it. There can be no real necessity for the expansion joints on this line being placed closer than at every fourth bent, or, say, from 175 to 200 ft. apart, and such an arrangement would add a great deal to the rigidity of the structure.

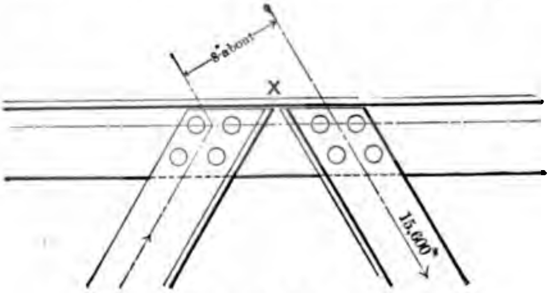


FIG. 43.

"9. *Resting Longitudinal Girders on Top of Cross Girders Without Riveting Them Effectively Thereto.*—The attachment of longitudinal girders to the cross girders on the Second Avenue line is the same for both fixed and sliding ends, except that the holes for the bolts used in the connections at sliding ends are slotted and are provided with washers, while for the fixed ends the holes are made to fit the bolts or rivets. The connection of longitudinal girders to the cross girders is not well designed to transmit the longitudinal thrust from the former to the latter. The bolts connecting the ends of the lower flanges of the longitudinal girders to the cross girders are missing in a great many instances, especially in portions of the structure on curves.

"The end details of these longitudinal girders have a great deal to commend them from a manufacturer's point of view, as they are simple, and no special details whatever are required for the sliding ends.

"10. *Cross Girders Subjected to Horizontal Bending by Thrust of Trains.*—No struts are used on the Second Avenue line in any case to carry the thrust from braked trains to column direct, but the cross-girders are relied upon to carry this load in bending. Throughout the entire line all cross-girders are composed of two separate girders, each of four angles and a solid web plate, or a lattice web system. These girders have stay plates between them at all points where the longitudinal girders connect to the cross-girders, so these heavy cross-girders are probably amply strong to carry all transverse bending that comes upon them in portions of the structure where the columns are located in the street beneath the tracks. But on portions of the structure where the columns are placed on curbs, the bending should be taken care of by means of struts extending out to the columns. On some of the down-town portions of structure with the columns located on curbs, there is a perceptible canting of the cross-girders when the brakes are applied to passing trains, and the writer was told by persons in a position to know that this torsion on the cross-girders is the cause of a great many rivets and bolts working loose.

"11. *Cutting Off Columns Below the Bottom of Cross Girders and Resting the Latter Thereon.*—The columns on this line are all cut off below the bottoms of cross girders and are provided with cast-iron caps which are bolted to the tops of columns and to the cross girders. The cross girders are double, as previously described; therefore they furnish quite a large bearing area on top of columns. A large plate 1 in. thick is inserted between the cast-iron cap and the bottom of cross girders, and about twelve ⅞-in. bolts are used in the connection of cross girders to columns. This detail, of course, does not fix the tops of columns in such a rigid way as the details used on the Union Loop of Chicago, but the connection is as strong in every way as it is possible to make it when the columns are cut off below cross girders. The writer could find none of the bolts in these connections loose, and he was informed by others that only a very few of these bolts had ever been replaced.

"No diaphragms are used between the cross girders directly over the columns, and it occurred to the writer that if a solid diaphragm had been put in between the two cross girders, directly over the center of the column, riveted to both girders and bolted to the top of column, it would practically have made a fixed end of the top of column, so far as the cross girders are concerned. Such details for tops of columns cannot be commended, because the only rigidity which can be obtained in such connections is due to the ability of the bolts to resist direct tension, and certainly better results can be obtained at much less cost by running up the columns and riveting the cross-girders into them.

"12. *Paltry Brackets Connecting Cross Girders to Columns.*—The brackets used on the Second Avenue line are small cast-iron sections curved to circular form and bolted at one end to the cross girders and at the other to the column. If these brackets were put on merely to improve the appearance of the structure, they may, to a certain extent, be said to fill the purpose for which they were intended, but if they were intended to serve as braces to aid the column in any way, they are certainly useless.

"13. *Proportioning Columns for Direct Live and Dead Load and Ignoring the Effects of Bending Caused by Thrust of Trains and Lateral Vibration.*—The columns used on this Second Avenue line are of Phœnix sections and contain ample metal to resist all stresses that ever come upon them if they were firmly fixed at the tops in both transverse and longitudinal directions. The vibration in this structure is not due to lack of metal in columns, but to numerous defective details as outlined previously. While there is considerably more vibration in this structure than there should be, it is, nevertheless, the most rigid and durable of any of the elevated roads in New York, excepting the Suburban Rapid Transit line and the City Hall approach, and the better condition of this Second Avenue line is due largely to the great amount of metal used in its construction. As nearly as the writer can estimate the weight of this structure, it contains about 30 per cent. more metal per lineal foot of structure than does the Union Loop of Chicago. A large portion of this metal is in the columns and cross girders.

"As before stated, the Phœnix columns on this line are often burst by the freezing of accumulated water on the inside of the columns. This water must get into the column by the bolt holes at top, through which the bolts pass that attach the cross girders to the column, also through the holes in the sides of columns through which the bolts pass that connect the curved cast-iron brackets.

"14. *Omission of Diaphragm Webs in Columns Subjected to Bending.*—The Phœnix column requires no diaphragm and is well adapted to carry shear in any direction.

"15. *Ineffective Anchorage;* 16, *Column Feet Surrounded by and Filled with Dirt and Moisture;* 17, *Inefficient Bases for Pedestals.*—The bases of the columns are made of cast iron, and into these cast-iron bases the column is set in cement or rust grouting. The joints between the columns and castings are in good condition, and there are no evidences of any springing or movement of the columns. The cast-iron bases are extended far enough above the ground to prevent the dirt and moisture from accumulating around the steel column. The columns are not badly rusted, considering the length of time this structure has been built. Each of these cast-iron bases is anchored to the masonry by four anchor bolts which extend to the bottom of pedestal. The anchorages are so strong that the columns and pedestals would act as one piece if tested to destruction. There have been but few if any repairs made to the anchorages and pedestals, nor has there been any settlement of the foundations. It is the opinion of the writer that the pedestals, bases and anchorages are first class, and if all parts of the structure were as well designed as these portions there would be but little adverse criticism to make.

"From the foregoing you will note that the writer does not agree with Mr. Clarke's statement that the Second Avenue line conforms in general design to all of the seventeen essentials named in your paper, and maintains that Nos. 1, 2, 5, 8, 9, 10 and 11 of the defects named do exist in a very distinct form in the Second Avenue line, and that the evil results of such defects are plainly shown by the action of the structure under loads and by the necessity for repairs which are being made from time to time.

"Mr. Clarke's figures of $319 per mile per year seem a large amount to pay out for repairs to metal-work alone, exclusive of painting and trackwork. The writer is of the opinion that on a structure designed like those shown in your paper, the cost of repairs to metal-work alone would be practically nothing for the first 20 or 30 years; and with no increase in the live loads, the life of such a structure, kept well painted, would be indefinitely long.

"The writer wishes it to be understood that he does not criticise the design of the Second Avenue line as not being fully up to the standard of good construction at the time it was built, and he appreciates the fact that the art of steel construction was in its infancy 20 years ago, and that it has been by a process of evolution that the designs of to-day are so far superior to those of the earlier days.

"*General Criticism of All the Elevated Railways in New York and Brooklyn.*—In accordance with your request, the writer extended his investigations to all the elevated railways in New York and Brooklyn, and in the following report will take up the 17 defective points mentioned in your paper, and apply them to all of these lines, and will show that some of these exist in all of the structures mentioned, and all of them in some of the structures.

"1. *Insufficiency of Rivets for Connecting Diagonals to Chords of Open Webbed Girders.*—The longitudinal girders on the Third Avenue line were originally made with single intersection webs, each diagonal being composed of two angles; but with increased live loads and constant traffic these girders began to wear out so rapidly that it became necessary to strengthen them. This strengthening was done by putting in another set of diagonals, each diagonal being composed of two flat bars which pass between the original angle diagonals at their centers and are riveted to them at their intersection by one rivet. No connecting plates are used in any of the connections of diagonals to chords, and even with the additional set of diagonals the girders are weak.

"If the loads were equally distributed between the two sets of diagonals, the number of rivets in the connections of diagonals to chords would be ample; but, as the added diagonals are capable of taking tension only, they are of but little value, and the end connections are still overstrained, as is shown by the number of loose rivets to be found in them.

"The construction of the longitudinal girders in the Ninth Avenue line is very similar to that of the Third Avenue line.

"The longitudinal girders in the Kings County Elevated are of much better design; for in most cases plenty of rivets are used, as the diagonals are connected to web plates in top and bottom chords.

"2. *Failure to Intersect Diagonals and Chords of Open-Webbed Girders on Gravity Lines.*—On none of the lines where lattice girders are used has there been any attempt to intersect the diagonals on gravity lines, and this is no doubt one of the great causes for the wear on these girders."

"4. *Failure to Proportion Top Chords of Open-Webbed Longitudinal Girders to Resist Bending from Wheel Loads in Addition to Their Direct Compressive Stresses.*—No webs are used in the top chords of longitudinal girders in any of the New York lines, but as the panels are very short in most instances, the bending on top chords from wheel loads does not produce excessive strains in them.

"On the Kings County Elevated, heavy web plates about 15 ins. wide are used between both top and bottom chord angles, which are ample to resist the bending from wheel loads in addition to the direct stresses. The connections are eccentric, and the stresses due to the bending from eccentric connections are greater than those from the bending due to loads on top chords.

"To make a comparison of the details of the longitudinal girders used on the Union Loop in Chicago, and some of the New York and Brooklyn elevated roads, the writer herewith gives some typical details of the different designs in Figs. 44, 45, 46 and 47.

"By a careful inspection of Fig. 44, which shows the details of the longitudinal girders used on the Union Loop, it will be seen that all diagonals intersect on the center-of-gravity lines of the chords, thus eliminating all secondary stresses, while the diagonals of girders shown in Figs. 45, 46 and 47, do not intersect on gravity lines; consequently large secondary stresses are produced in all said designs.

"It will also be noticed that in the Union Loop design ample provision has been made for bending on top chords, by providing a web plate between the two top chord angles, that large connecting plates are used for connecting diagonals to bottom chords, and that more rivets are used in all connections of diagonals than in the girders of the other structures.

"The girders for the Kings County Elevated, Fig. 45, have heavy web plates in top and bottom chords, and, although more metal is used in these girders than in those for the Union Loop, none of the diagonals intersect on gravity lines. The end detail of these girders which furnishes the bearing on cross girders is very eccentric, and it will be seen that on the section on *AB*, Fig 45, there is a large bending moment which must be taken up by the top chord and the reinforcing angles at the end, but the reinforcing angles are cut off so near the point of maximum bending that there is a great shear on the few rivets back of the section line *AB* which could easily have been avoided by extending the reinforcing angles back 12 or 15 ins. farther.

"Fig. 46 shows the details of the longitudinal girders on the Second Avenue line, which have been considered previously.

"Fig 47 shows the details of the longitudinal girders on the Third Avenue line since they have been reinforced. The eccentric connections, light top chord section, and few rivets in all connections should be noted.

"There is one commendable feature of the girders shown in Figs. 45 and 46, which that shown in Fig. 44 does not possess, and that is the projection of the top flange angles above the cross-girders. This arrangement of girders gives an unbroken surface of longitudinal girders on which to lay the ties.

"5. *Insufficient Bracing on Curves.*—No special lateral bracing is used on curves of any of the New York and Brooklyn lines.

"6. *Insufficient Bracing between Adjacent Longitudinal Girders.*—On the Second Avenue, the Third Avenue, and the Ninth Avenue lines, both the top and bottom flanges of adjacent longitudinal girders are braced together with angles connected to girders by two rivets, no connection plates being used in any case. On all of these lines there are loose rivets in the bracing connections.

"7. *Pin-Connected Pony Truss Spans and Plate Girders with Unstiffened Top Flanges.*—Pony truss spans are used on the greater portion of the Sixth Avenue line, and of all the structures which the writer has examined, this one is undoubtedly in the worst condition. The evidences of wear and tear are too numerous to mention. The vibration is excessive, and loose rivets are plentiful.

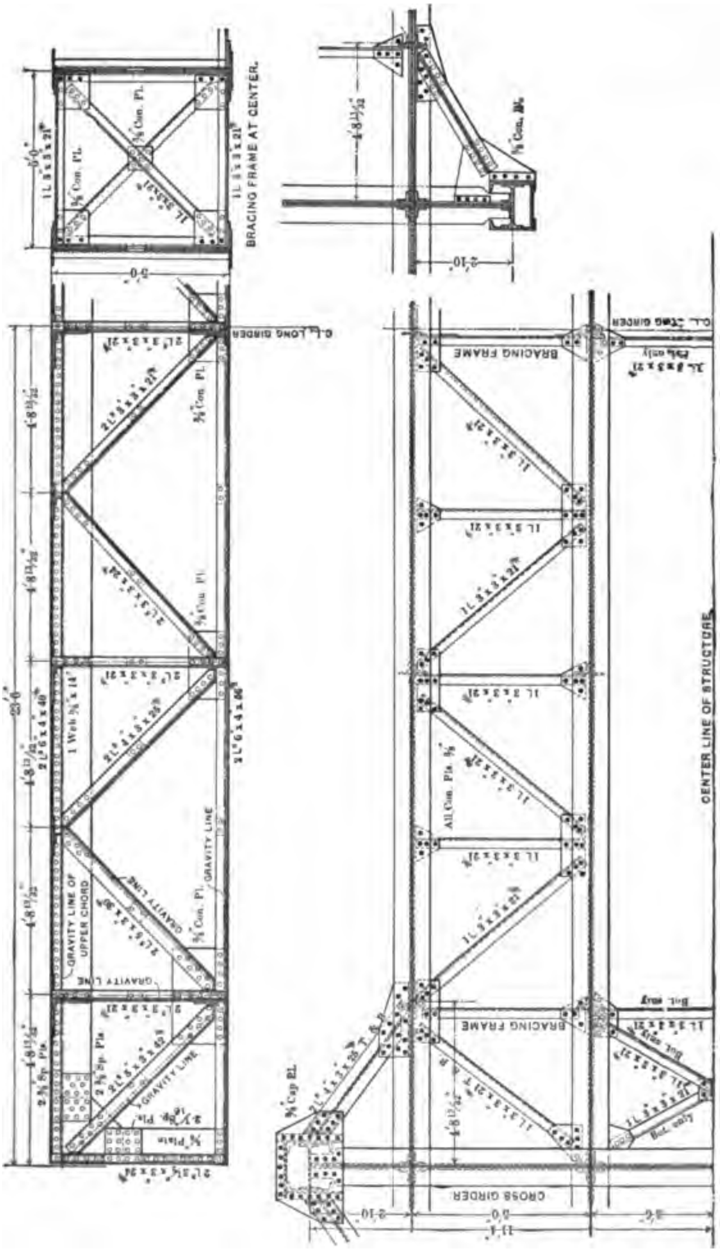

BRACING FRAME AT CENTER.
3/8 Con. Pl.
C. L. LONG GIRDER
GRAVITY LINE
GRAVITY LINE OF UPPER CHORD
1 Web 3/8 x 14
3/8 Plate
3/8 Cap Pl.
All Con. Pls. 3/8
BRACING FRAME
CROSS GIRDER
CENTER LINE OF STRUCTURE
3/8 Con. Br.
2-10
8-0
5-0
23-6
11-4
1 L 3 x 3 x 21
2 L 3 x 3 x 21

FIG. 44.

"8. *Excess of Expansion Joints.*—With two or three exceptions, all of the lines in New York and Brooklyn have expansion joints at every panel. Two of the exceptions are the Fifth Avenue line in Brooklyn, in which the sliding ends are placed at every third bent, or about 150 ft. apart, and the Suburban Rapid Transit line, in which they are placed at every fifth bent, or about 225 ft. apart. The longitudinal rigidity gained by spacing the sliding ends as in the last-named structure is very noticeable by comparing them with the structures in which the expansion joints are placed in every panel.

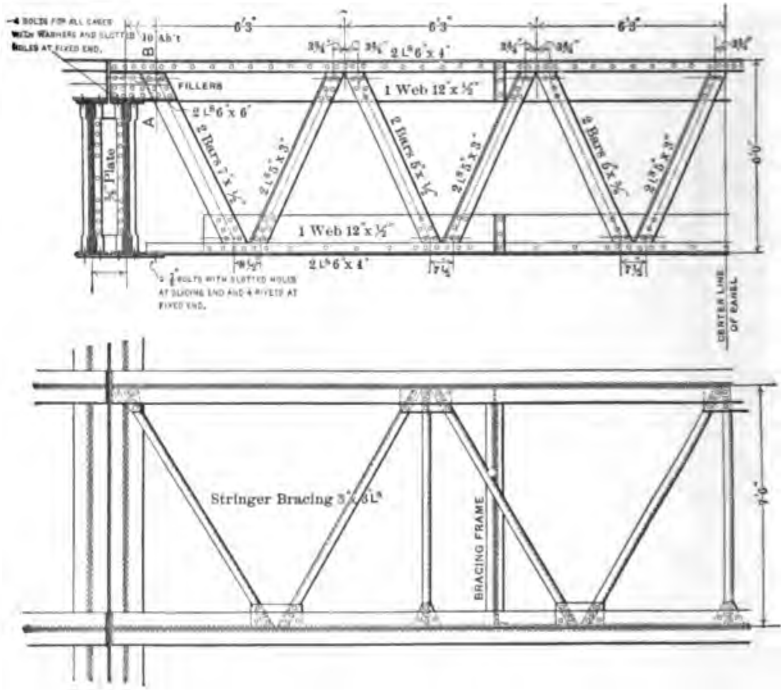


FIG. 45.

"9. *Resting Longitudinal Girders on Top of Cross Girders Without Riveting Them Effectively Thereto.*—Various details are used on the different lines for attaching the longitudinal girders to cross girders. The details adopted on the Kings County, the Second Avenue, and the Third Avenue lines are shown in Figs. 45, 46 and 47, and these are typical of those used on all of the older lines. On the Suburban Rapid Transit line in New York, and the Fifth Avenue line in Brooklyn, the longitudinal girders are riveted into the cross girders, the top flanges of the former passing beneath those of the latter.

"The connections of longitudinal girders to cross girders on the older lines are not designed to resist properly the thrust from braked trains, as will be seen from Figs. 45, 46 and 47.

"A great many of the rivets and bolts attaching the longitudinal girders to the cross girders work loose, especially those at bottoms of longitudinal girders.

"10. *Cross Girders Subjected to Horizontal Bending by Thrust of Trains.*—On none of the lines in New York or Brooklyn is any special bracing used to carry the thrust from braked trains directly to the columns, and thus relieve the cross girders from the transverse bending which comes upon them. A slight semblance of such bracing is used on the Kings County Elevated, but the struts are of small single angles, which are placed in planes of bottoms of longitudinal girders only, and are not capable of carrying the stresses which come upon them.

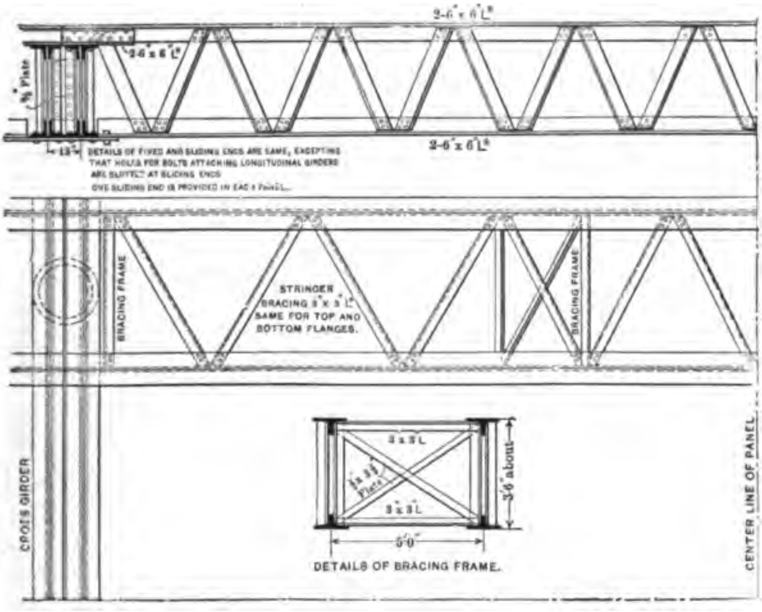


FIG. 46.

"On most of the older structures the cross girders are all double, consequently they are capable of carrying more horizontal bending than are single-webbed girders, and when the columns are placed beneath or quite near the tracks, they are strong enough to carry the thrust to the columns; but where columns are set on curbs, the bending effect of braked trains is noticeable in the vibrations of the structure, and in some cases by the canting of the cross girders.

"The bracing used on the Union Elevated Railway of Chicago to take up the thrust from braked trains, also to fix the tops of columns, is shown in Fig. 44. From some of the discussions, the writer believes it will be interesting to give in this connection the method used in determining the size of these struts and the strength of their details.

"Let us assume the span length to be 50 ft.; live load = 1,800 lbs. per lineal foot of track (equivalent load for 150 ft. span); total live load on one panel per track = 50 x 1,800 = 90,000 lbs.; co-efficient of friction = 0.20; longitudinal thrust = 90,000 x 0.20 = 18,000 lbs.; distance from center to center of columns = 22.66 ft.; thrust on one column $= \dfrac{18{,}000 \times 17.33}{22.66}$ = 13,770 lbs.; the depth of longitudinal girder is 5 ft., unsupported length of column = 16 ft. (see Fig. 48).

"As this bracing is designed to fix the tops of columns, and as the bottoms of columns are firmly fixed by the anchorages, the lever arm is equal to one-half the unsupported length of column, or 8 ft.

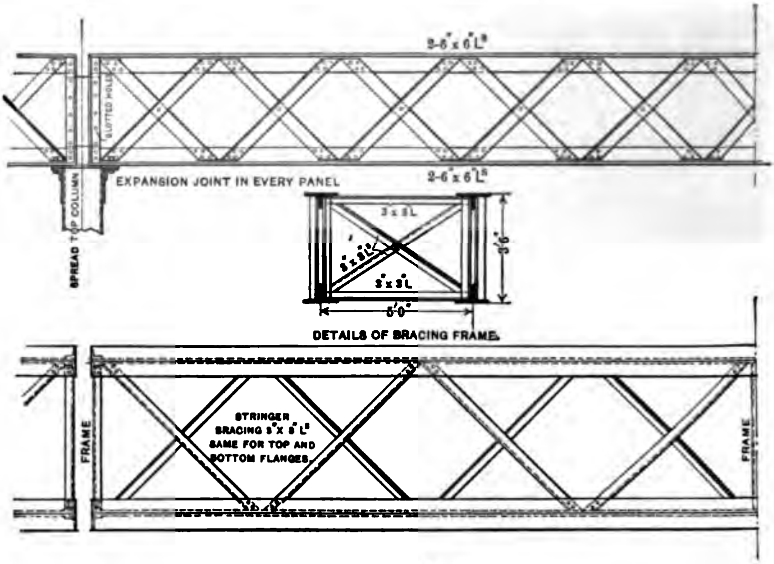


FIG. 47.

$$\text{Stress on lower strut} = \frac{13 \times 13{,}770}{5} \sec.\ \theta = 42{,}246 \text{ lbs.}$$

$$\text{Stress on top strut} = \frac{8 \times 13{,}770}{5} \sec.\ \theta = 25{,}998 \text{ lbs.}$$

"The unsupported length of these struts is about 4 ft. Least radius of gyration, two 4 x 3-in. 25-lb. angles = 1.2. Therefore, $\dfrac{l}{r} = \dfrac{48}{1.2} = 40$. Hence, these struts are good for 12,000 lbs. per square inch. They are, therefore, strong enough to fix the tops of columns. From Fig. 44 it will be seen that eight rivets are used for the bottom struts; then stress on each rivet in the connection for bottom strut $= \dfrac{42{,}246}{8} = 5{,}281$ lbs., and for those in the connection for top strut $= \dfrac{25{,}998}{6} = 4{,}333$ lbs. These stresses are well within ordinary working intensities. From these calculations, it will be seen that the tops of columns are fixed by these struts, and that all members and details are strong enough to take care of the stresses produced by the assumed thrust of 0.20 of the live load.

"Having thus shown the method used in determining the size of struts required to fix the tops of columns, the effect of this horizontal thrust will now be used in proportioning a column.

"Assuming the same span length as before, we have the following:

"Live load = 2,440 lbs. per lineal foot of track (equivalent live load for 50-ft. span).
"Dead load = 650 lbs. per lineal foot of track.

"Total = 3,090 lbs. " " "

"Total load on one column from longitudinal girders .... 3,090 x 50 = 154,500 lbs.
"Weight of one column and half of one cross-girder... 6,500 "

"Total direct load on one column.................... 161,000 "

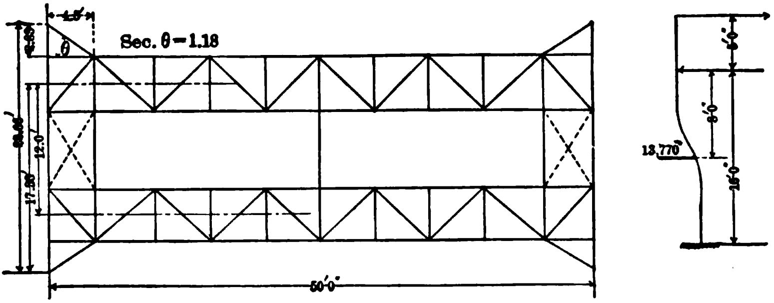


FIG. 48.

"The total longitudinal thrust on one column, as given above, is 13,770 lbs. One-half unsupported length of column = 8 ft. or 96 ins. Bending on column = 96 x 13,770 = 1,321,920 inch-pounds. Section used for column $\begin{cases} \text{2 15-in. 100-lb. channels.} \\ \text{1 15-in. 123-lb. I-beam.} \end{cases}$ Area of section = 32.3 sq. ins.

"The web of I-beam is placed parallel to center line of structure.

"The moment of inertia of section = 1,300 net.

"Therefore the stress on extreme fiber $= \dfrac{8 \times 1,321,920}{1,300} =$ 8,135 lbs.

"Stress from direct load = 5,000 "

"Total stress on extreme fiber due to combined direct load and bending moment = 13,135 "

which is allowable under such an unusual loading, as $\dfrac{l}{r}$ is less than forty-five.

"From the foregoing calculations it will be seen that all parts of the structure are designed to resist properly the assumed horizontal thrust; and it is interesting to note also that, although all possible combinations of stresses under the most unfavorable conditions are properly taken care of, the structure does not weigh as much per lineal foot as some of the older designs in which no provision is made for such stresses, although they are liable to occur.

"11. *Cutting Off Columns Below the Bottom of Cross Girders and Resting the Latter Thereon.*—The columns of nearly all the structures in New York and Brooklyn are cut off below the bottoms of cross girders, except in the City Hall approach in New York, and on a portion of the line on Broadway in Brooklyn. On the City Hall approach the columns are built of two 15-in. channels, laced together with double-riveted lacing. The inner channel is cut off below the bottom of cross girder, and the outer channel is extended to the top of cross girder, the latter being riveted into this channel. This construction is certainly much better than that used on most of the New York lines; but the connection would be more rigid if both channels were extended to top of cross girder, and if a diaphragm were placed between the two channels and extended down to the bottom of the curved bracket beneath the cross girder.

"The details used for attaching the cross girders to columns on the Rapid Transit line, New York, and given by Mr. Berger in Fig. 35, is certainly a good one, as it makes the cross girder and column practically continuous, and is at the same time comparatively easy to manufacture and erect.

"On all lines where Phœnix columns are used, the columns are cut off beneath the cross girders, and are provided with cast-iron caps to which the cross-girders are attached by means of bolts. This style of construction, with its defects, was discussed in connection with the Second Avenue line.

"On the Third Avenue line the columns are composed of two 15-in. channels connected with double-riveted lacing, and are flared out at the top to receive the longitudinal girders which rest thereon. The connections between columns and girders are very weak, and are not capable of resisting properly the longitudinal thrust.

"The curving of channels at tops is objectionable, for, according to the reports of shop inspectors, the channels often crack while being bent. Another objectionable feature of this style of column is that where the concentrations from longitudinal girders come upon the edge of the column, there is very little metal to carry the load. There are many failures in the details at tops of the columns on the Third and Ninth Avenue lines, and in many instances bent plates have been used to reinforce them.

"The bolts and rivets which attach the longitudinal girders to the tops of columns fail in a great many instances, and in some cases the tops of columns have been reinforced with bent plates. A portion of the Ninth Avenue line is constructed in the same manner. On the Fifth Avenue line in Brooklyn the columns are built of two 15-in. channels with double riveted lacing bars. The inner channel is cut off below the bottom of cross girder, and the outer one is extended up about 18 ins., and riveted to end of cross girder. The detail is similar to that used on the City Hall approach, but not nearly so good.

"12. *Paltry Brackets Connecting Cross Girders to Columns.*—The brackets used on the Second Avenue line have been described, and the same style of brackets is used on all structures having Phœnix columns.

"The columns on Third Avenue are flared out at top and thus form a kind of bracket. The brackets on the Sixth Avenue line are made of a single 3-in. or 4-in. T-iron and connected to columns and cross girders by four small rivets about ⅝ in. in diameter, at each end. These brackets are absolutely useless so far as providing any lateral rigidity to the structure is concerned.

"On the Kings County Elevated the brackets are made of two 3 x 3-in. angles connected to cross girders and columns by three rivets or bolts. These brackets are very weak, and add but little, if any, rigidity to the structure.

"A portion of the Fifth Avenue line in Brooklyn has brackets composed of two 6 x 6-in. angles attached to cross girders and columns by four rivets at each end of strut. These brackets are strong enough to take care of any stress that comes upon them. On some portions of this line, where the structure is only of ordinary height, the brackets are omitted, and as the connection between cross girders and columns is weak, as previously described, the tops of columns are almost free ended. This portion of the structure is very vibratory, in fact the writer believes the vibration at the Sixteenth Street station on this line is greater than at any other elevated station in New York or Brooklyn.

"The City Hall approach has curved brackets with solid webs which serve their purpose well.

"The brackets on the Suburban Rapid Transit line are made of two 4 x 3-in. angles, bent at ends on to cross girders and columns, and connect by six rivets. These brackets, and the superior details used to connect the cross girder to column help to make the structure rigid transversely.

"13. *Proportioning Columns for Direct Live and Dead Loads and Ignoring the Effects of Bending Caused by Thrust of Trains and Lateral Vibration.*—If all details were made so as to fix properly the tops of columns in both transverse and longitudinal planes, the sections used for the columns on most of the lines in New York and Brooklyn would be strong enough to carry satisfactorily all the loads that could ever come upon them.

"14. *Omission of Diaphragm Webs in Columns Subjected to Bending.*—A great many of the columns used on the various lines are of Phœnix section, and consequently do not require diaphragms, and on several lines where channel columns are used the lacing is double riveted. The writer could see no signs of failure in any of the lacing on columns, even where single riveted lacing is used.

"15. *Ineffective Anchorages.*—The writer believes that the anchorages on nearly all the lines he examined are strong enough to carry satisfactorily all the combinations of stresses which ever come upon them.

"16. *Column Feet Surrounded by and Filled with Dirt and Moisture.*—There are a number of designs used for column feet on the different lines in New York and Brooklyn, but in nearly all cases the bases are made of cast iron, and are extended well above the surface of the ground, serving as fenders where the columns are placed in the street. The feet of the Phœnix columns are, in general, as well preserved as could be expected considering the age of these structures, and the little attention these bases have received. If the feet of columns were kept properly painted, and if the joints between the columns and the cast-iron bases were kept well filled with grouting, these bases would be entirely satisfactory.

"The bases of columns on the Third and Sixth Avenue lines and on a portion of the Ninth Avenue line are very different from those used with the Phœnix columns. As well as the writer could determine, these columns, which are in the street, are set in a cast-iron base which is entirely below the surface of the pavement, and a separate cast-iron fender is used above. These bases are not so satisfactory as those previously described, and in many cases the fenders are broken and the feet of columns are badly rusted.

"The column bases on the Suburban Rapid Transit line are made of cast iron and the bottoms of columns are filled with grouting. The feet of these columns are in good condition.

"On a portion of the line on Broadway in Brooklyn, the bases are made of cast-iron and are solidly riveted to the feet of columns. These castings rest on stone pedestals which project 18 ins. or 2 ft. above the pavement and serve also as fenders. These column feet are in excellent condition; the connections of columns to bases are very strong, and their bases are in turn attached to pedestals by four anchor bolts. There is no place for moisture or dirt to accumulate, and for durability and efficiency these bases are probably superior to those used on any of the other elevated lines in New York or Brooklyn.

"*17. Insufficient Bases for Pedestals.*—The writer could not secure much information concerning the pedestals, but so far as he could learn there has never been any trouble from the settlement of foundations, and therefore it is probable that ample bases have been provided for the pedestals.

"18. *Neglect of Painting the Metal-work.*—It is surprising to note the false economy practiced on all the elevated railways in New York and Brooklyn, by failing to keep the metal-work properly painted. It is safe to say that there is not a single line which is not badly in need of repainting.

"Without doubt the almost unmolested erosion of the metal on the older structures has done more to destroy them than the wear and tear due to both the heavy traffic and the excessive vibration from defective details. It is only a matter of time, and not a very long time either, unless some very effective means are employed to arrest the ravages of rust, until the older structures will have to be rebuilt. It is indeed remarkable that metal-work, the value of which runs up into millions of dollars, should be left to rust away, when a comparatively small sum of money, spent at the proper time and for the right kind of painting, would prolong the life of the structure indefinitely. The writer believes that the subject of painting should have received more consideration in your paper, as it is certainly a most important one. Engineers should certainly use their influence to prevent such great losses to the companies, which losses are as sure to come from lack of painting as from faulty details."

From what Mr. Hedrick says it will be seen that Mr. Clarke was a trifle hasty when he stated that the Second Avenue line of New York "conforms in general design to all of his (the author's) sixteen 'essentials,' although in details there are many differences." In truth, there are very few of the essentials of good construction that were not violated in the design of this Second Avenue line; although there is this to be said in its favor—a plentiful, or, strictly speaking, an extravagant, use of metal reduces considerably the magnitude of the ill effects of the violation of first principles of design; and, considering the lack of knowledge about structural metal-work at the time it was designed, it is a creditable piece of engineering. Nevertheless, this is no reason why it should continue to be a model for future elevated railroads.

Treated versus Untreated Timber.—It appears that Mr. Stuart and Mr. Belknap question the correctness of the data used in comparing the real values of vulcanized and untreated timber, so it behooves the author to make good his premises.

Most of his information concerning vulcanized yellow pine was obtained in conversation with the late Colonel Hain, who was for many years general manager of the Manhattan Railway Company. Unfortunately, there is no documentary evidence to verify the conversation mentioned, but the author is able to give the following extract from a letter by Colonel Hain to Professor F. Holbein, of Berlin, Germany, which will substantiate the statement that the former approved of vulcanized timber for elevated railroads:

> "We first began the use of vulcanized wood in the spring of 1883. One million feet of vulcanized cross-ties and planking was placed on the line of our road that year, expressly to give it a fair trial on its merits. After the lapse of six years, a careful and critical examination was made of the vulcanized material laid in 1883. We found it entirely free from decay, and as sound and sweet as the day it was laid. There were no indications of decay at the end of the vulcanized planking, while the planks and cross-ties not treated, placed on the structure at the same time, were decayed at the ends and where they were nailed or bolted to the supporting timbers.
>
> "Since the foregoing examination, we have been using vulcanized material exclusively on the line of the road. Actual experience has satisfied us that vulcanizing is far superior to any other known treatment for prolonging the life of timber. We find that vulcanized material neither wears out nor decays. We have had no occasion to take up any of it since we commenced its use.
>
> "Our experience with creosoted ties proved unsatisfactory. Creosoting seems to soften timber and weaken its spike-holding quality. We have found great trouble in keeping spikes in place, especially on curves. Spikes in vulcanized wood we find are as firmly fixed after the lapse of ten years as when first driven.
>
> "Vulcanized wood does not seem affected by wind, rain, heat or sun. Before we adopted vulcanized wood it was necessary to constantly employ 150 men painting our structure. Since its adoption, we have only 60

painters, who work on the iron part of the structure exclusively. Vulcanized wood needs no paint to protect it.

"The average life of untreated ties and timber on our structure has been about five to six years."

Here is a distinct disagreement between Mr. Stuart and Colonel Hain concerning the life of untreated timber on elevated railroads. Mr. Stuart challenges the author's assumption that the life of such timber is as short as seven and a half years, while Colonel Hain says that on his lines it has been about five or six years. The author's experience with timber trestles in various parts of the United States indicates a life of from five to eight years for untreated yellow pine, although in certain cases two years' longer duration has been obtained by renewing defective parts and bolstering up the structure in different ways.

In order to satisfy Mr. Belknap's doubts concerning the efficiency of the vulcanizing process and the comparative values of vulcanized and untreated timber, the author has collected quite a mass of written evidence, extracts from which are given in the appendix.

Bearing Capacity of Chicago Soil.—The author regrets that, as pointed out by Mr. Weston, his statement that Mr. Rowe found the safe load per square foot for Chicago soil as low as 1,000 pounds, should cause any misconception concerning the character of the foundations for the Northwestern and Union Loop Elevated Railroads. Mr. Rowe's discussion, though, will clear up any such misunderstanding.

Best Style of Anchorage for Columns.—Answering Mr. Nichols' statement that the author duplicated in his column anchorage for the Sioux City train shed the corresponding detail used for the St. Louis Union Depot, the author would reply that the design for the former was made in June, 1891, before anyone did any figuring at all on the St. Louis train shed.

Best Sections for Columns.—Answering Mr. Nichols' statement that no one has ever made a very satisfactory column from I-beams, and that the Z-bar column is "unsatisfactory when it comes to connections with girders or with column feet," the author must take issue with him; for it would be difficult to evolve a more satisfactory column for street work than that formed of two channels with an I-beam between, as used throughout the Union Loop. The author does not mean satisfactory to the manufacturer or to the erector, but satisfactory to the party who pays for and operates the structure. These columns are not only extremely rigid, but also are well calculated to resist deformation from the heavy blows to which they are occasionally subjected by the street traffic. As for the Z-bar column of the Northwestern Elevated, one could not ask for better connections for detailing; and certainly the column thns far has proved satisfactory in every respect, although it has not yet been subjected to the test of traffic.

Replying to Mr. Nichols' question as to why the columns for Designs 12 and 13 have larger sections than those for Design 3, the author would state that the latter design involves the use of longitudinally braced towers, while the other designs do not. In Design 3 there is only direct vertical load on the columns, while in the other designs there are both vertical load and cross bending.

Mr. Connor criticises the Z-bar column on account of its expense in manufacture; but when one considers that when the Northwestern metal-work contract was let the pound price bid was very much lower than any price previously tendered on elevated work, notwithstanding not only the alleged difficulty in manufacturing the columns, but also the reaming clause, the importance of his criticism reduces practically to zero. It must be remembered that the ultimate object in designing metal-work is to obtain results and not to keep down to the lowest possible limit the cost of manufacture.

The columns of two channels with flared ends advocated by Mr. Connor are defective for two reasons: first, the bending is injurious to the metal, and, second, the bearings for the longitudinal girders are inadequate. Mr. Hedrick refers to these points in his report upon the New York and Brooklyn elevated railroads.

Best Style of Expansion Joint.—The author never claimed that he evolved his design for expansion pockets out of his inner consciousness. It represents simply an improvement on the older designs, in that the load from the longitudinal girder is applied as closely as practicable to the web of the cross girder, and in that the weight of metal required is reduced to about a minimum, with due regard for both direct load and bending caused by eccentricity.

Distance Between Expansion Joints.—In respect to the best distance between expansion joints, the author would call attention to the fact that when the columns are fixed at top and bottom the effect of variation of temperature is greater than where one end is loose, and that the extremes of temperature in Chicago are somewhat greater than those at New York. On these accounts he still prefers to adhere to 150 ft. as the regular limit, with an occasional length of 200 ft. at most, where the conditions necessitate it. The author's calculations were based upon an assumed extreme of expansion and contraction equal to 1 in. in 100 ft., although he considered it probable that not much more than three-quarters of this would be found after erection.

Superelevation on Curves.—Mr. Nichols must remember that it is intended to operate the Northwestern Elevated at much higher speed than ever before adopted for an elevated railroad, hence the author's "apology for a compromise between theory and practice in using low elevations of the outer rail on curves."

Answering Mr. Nichols' surmise that none of the connections of the author's columns to girders are either very simple or thoroughly effective, the author begs to submit through Mr. Hedrick's report some detail sketches of the tops of the columns for the Loop. From these sketches it will be seen that the column tops are connected rigidly by an ample number of rivets to substantial struts that form part of a complete system of lateral bracing, and that the connecting rivets are in direct shear. It is shown by these sketches that "close adherence to the scholastic methods has not led to the retention of some of the antique errors of girder construction."

It is evident from Mr. Nichols' figures that the spans on his Brooklyn Elevated could have been made a trifle shorter, so far as economy is concerned; however, if he will deduct the cost of all the lateral bracing, and will compare that of the longitudinal girders alone with that of the bent, he will not find as much difference as 30 per cent. It is very easy to see that if the cost of a bent be practically constant for small changes in length of longitudinal girders, and if the cost per foot of the latter vary directly with the span, the greatest economy will exist when the cost of a bent is equal to the cost of the longitudinal girders of one span.

In order to reply to Mr. Nichols' claim that an earth embankment with concrete retaining walls would be cheaper than the structure adopted for the Northwestern Elevated, the author has made such a design with an estimate of cost, and finds that, on the contrary, the embankment would cost fully 7 per cent. more. The data for the estimate are as follows:

Height of embankment above street, 16 ft.; width of embankment out to out, 48 ft.; thickness of both wall and buttresses at top, 18 ins.; thickness of wall at top of footing course, 3 ft.; that of buttresses at same elevation, 6 ft.; width of footing course for wall, 5 ft., and that for buttresses, 8 ft.; depth of foundation, 5 ft.; front face of wall vertical; rear face stepped off by 6-in. offsets; three horizontal 1½-in. rods used to tie together each pair of opposite buttresses transversely to line; vulcanized ties 8 ins. x 8 ins. x 9 ft. spaced 2 ft. centers; price of concrete $7 per cubic yard; cost of metal 2.5 cents per pound; cost of earth in place 30 cents per cubic yard; cost of excavation, including back-filling, 50 cents per cubic yard; cost of rails for both cases, $2 per lineal foot of track; cost of vulcanized timber in place $36 per M ft. B. M.

The length of line considered is one city block of 292 ft., of which the street takes 72 ft. and the alley 20 ft., leaving exactly 100 ft. as the length of each retaining wall. As it is not practicable to tie together opposite buttresses in the end walls, the entire end walls were made of the same section as the buttresses of the side walls.

The following is the detailed estimate of cost:

Two Embankments.

Concrete	1,502	cu. yds.,	at $7.00	$10,514.00
Earth	4,187	“	“ .30	1,256.10
Excavation	782	“	“ .50	391.00
Ties	400		“ 1.75	700.00
Rails, etc.	800 ft. of track		“ 2.00	1,600.00
Metal	16,400 lbs		“ 2.5 cents	410.00
Grouting around the rods				200.00
Total				$15,071.10

Metal Structure over Alley.

Metal	20,000	lbs.	at 2.5 cents	$500.00
Floor	20	ft.	“ $23.00	460.00
Total				$960.00

Metal Structure over Street.

Metal	132,000	lbs.	at 2.5 cents	$3,300.00
Floor	72	ft.	“ $23.00	1,656.00
Pedestals	6		“ 100.00 (av.)	600.00
Total				$5,566.00

Summation.

Embankment	$15,071.10
Over alley	960.00
Over street	5,556.00
Total	$21,587.10

or, $73.93 per lineal foot.

Cost of Metal Elevated.

Metal, per foot, 1,765 lbs. at 2.5 cents	$44.13
Floor and rails, per foot	14.32
Pedestals (32 at $96) ÷ 292	10.52
Total cost per lineal foot	$68.97

The schedule prices used in these estimates are the same as those adopted for the preliminary estimates of cost for the Northwestern Elevated. Moreover, they have since proved to be almost exactly right, except that the concrete in foundations was somewhat cheaper; but as the concrete for the walls will be more expensive than that in the pedestals on account of the more complicated and larger forms required and the smooth finish of the exterior, it has been considered best to let the price stand unchanged.

The difference in cost per foot in favor of the metal structure is $4.96, or a little over 7 per cent.

The adoption of the embankment design would increase the cost of right-of-way almost as much as it would that of the construction, for, although it would not affect the price of the land occupied by the structure, it would affect the amounts to be paid as damages to adjacent property. These will average as high as 30 per cent. of the cost of the land occupied by the structure. The reason for the smaller damages for a steel structure is that with it the railroad company is able to grant to adjacent property owners access to the damaged property from the right-of-way, which could not be done were the embankment design adopted. The author has been informed by one of the officials of the Northwestern Elevated, who is best posted on right-of-way matters, that the additional amount to be paid for damages on account of the embankment design would be not less than 15 per cent.

The advantages of the embankment design are, first, a reduction in cost of painting to one-third of that for the metal structure, and, second, lowering the grade about 3 ft. To offset these there are the extra first cost of construction and right-of-way, the more rapid deterioration of the ties in the embankment, and the prevention of use of ground beneath the structure for storage purposes, small shops, etc. This last item is an important one, especially as the ground will become more and more valuable for such purposes as the city continues to grow and develop in the neighborhood of the line.

Answering Mr. Nichols' criticism of the design for anchor bolts, take the worst case on the Loop, where the spans are, say, 50 ft. long, making the distance between expansion points 150 ft., and load two of the three spans to the maximum, making the live load on one track about 200,000 lbs., for which the thrust would be 40,000 lbs., or 13,333 lbs. per bent. The spacing of tracks being 12 ft. and that of the columns 22 ft. 8 ins., the portion of the 13,333 lbs. going to the nearer column would be about 10,000 lbs. The greatest unsupported length of column, measuring from the under side of the thrust strut to the bottom of the base plate, is 25 ft.; and, as the column is fixed at both ends, the point of contraflexure will be at the middle, making the lever arm for the thrust 150 ins. and the overturning moment 1,500,000 inch-pounds.

In order to make all the conditions as bad as possible for the detail, no live load will be placed on the bent considered, and as the dead load per track, including weight of bents, is 800 lbs. per lineal foot, the dead load on the column is 40,000 lbs. It is difficult to say where is the centre of upward pressure to resist this weight; but, if it be assumed at the same distance from the axial plane as are the anchor bolts, or 9½ ins., no great error will be made. This makes the righting moment 380,000 inch-pounds, leaving for the net overturning moment 1,120,000 inch-pounds; dividing this by the 19 ins. between opposite anchor bolts gives about 59,000 lbs. as the stress on the two anchor bolts. As these are 1½ ins. in diameter, the intensity on the metal will be about 17,000 lbs., which, though high, is not excessive.

As this is the worst possible case, and as all the anchor bolts for the line pedestals are of the same diameter, there is evidently sufficient strength in all of these bolts; and, moreover, there is no great waste of metal in the anchor bolts for the shorter columns. Again, on various accounts one would not think of using bolts of much less diameter on account of possible future rust, especially as the diameter is reduced at the root of the thread.

The next matter is whether the anchor bolts project far enough into the concrete, as Mr. Seaman, Mr. Berger, and others appear to question the propriety of not carrying them down to the bottom. In the first place it must be noticed that the mass of concrete is truly monolithic; and, as the function of the bolts is to make the column and the concrete act as one piece in resisting overturning, it will suffice if the tensional strength of the concrete at the end of the bolts be as great as that of the acting bolts.

Now it must be noticed that only one pair of anchor bolts can act at a time, and that the ultimate strength of this pair is about 55,000 lbs. per square inch, or 194,000 lbs. The area of the concrete at the ends of the bolts is 49 sq. ft., or, say, 7,000 sq. ins. If the tension be distributed uniformly over one-half of this area, the intensity will amount to less than 60 lbs., which is far below the ultimate tensile strength of even the poorest concrete.

Now, as to whether the rods are long enough to distribute their pull into the concrete, above the anchor casting, past experiments prove that they are amply so: but, even if they are not, the anchor plates will provide a proper distribution without overstraining the concrete.

It is, therefore, evident that there is no necessity whatsoever for carrying the rods any lower than they were carried.

In connection with the pedestals there remains but one point to be taken up, viz., whether the pedestals themselves have weight enough to resist the assumed overturning for which the anchor bolts were proportioned.

In the worst case on the Loop, the point of flexure in the column of which is about 20 ft. above the bottom of the concrete, the base of the latter is 10 ft. square. Taking the center of moments at one edge of the base, the overturning moment is 200,000 foot-pounds. The total vertical load on the base is composed of the 40,000 lbs. of dead load on the column, the weight of concrete, which is about 66,000 lbs., and the weight of earth on top of the pedestal, which amounts to about 36,000 lbs., making a total load of 142,000 lbs.

If the resisting moment of the weight is limited to that existing when the intensity of pressure at one edge of the base reduces to zero, the lever arm of the resisting moment will be one-sixth of the width of base, or 1.666 ft., and the greatest resisting moment therefore will be 142,000 x 1.666 or about 236,000 foot-pounds.

It is therefore evident that, even if the earth about the pedestals were not tamped in, the pedestals are large enough to resist properly the overturning effect of the assumed thrust used in proportioning the anchor bolts.

As for the pedestals on the Northwestern Elevated, the conditions are quite different, the anchor bolts, of which there are but two per pedestal, being required primarily for the assumed transverse load of 600 lbs. per foot of span. If the length of the latter is taken as before at 50 ft., the total thrust is 30,000 lbs., or 7,500 lbs. per pedestal. The greatest unsupported length of column is about 16 ft., and, as both ends are fixed, the lever arm is 8 ft., making the overturning moment 60,000 foot-pounds. By assuming no train on the track of the column considered, the only load on the column will be the dead load, which amounts to about 32,000 lbs., and as its lever-arm is 7½ ins., the resisting moment will amount to 20,000 foot-pounds, making the net overturning moment 40,000 foot-pounds, or 480,000 inch-pounds, for which the lever arm is 15 ins., and therefore the stress on the single rod 32,000 lbs., or a little over 18,000 lbs. per square inch.

The point of flexure in the column is 17 ft. above the base of the pedestal, thus making the overturning moment 127,500 foot-pounds.

The total load on the base of the 8-ft. square pedestal consists of 32,000 lbs. on the column, the weight of the concrete, amounting to about 48,000 lbs., and that of the earth above the pedestal, amounting to about 20,000 lbs., making a total load of 100,000 lbs., for which, as in the previous case, the lever arm is one-sixth of the length of the base, or 1.333 ft., making the greatest righting moment 133,000 foot-pounds, which is a little more than the overturning moment, showing, as before, that, even if the earth in the pits be not tamped, the pedestals are of ample size to resist properly the greatest overturning moment of the assumed loading.

It is therefore proved that all the adverse criticism of the design of the pedestals on both the Loop and the Northwestern Elevated is without foundation, and that the consequent objections to these designs are purely imaginary.

Mr. Seaman says, referring to the New York and Brooklyn structures:

> "These elevated roads, after twenty years of service, under loads exceeding those for which they were designed, show no indication of such deterioration as would justify the prediction of the author that they will eventually be reconstructed because of their faulty details."

Perhaps Mr. Seaman will change his opinion about this after reading Mr. Hedrick's report. If on some of these structures 100 rivets per mile of double-track elevated road must be replaced each month by reason of their failure or working loose, as was stated to Mr. Hedrick, does it not show that the details are greatly overstrained and that the structure is in consequence gradually wearing out? The author's experience with ordinary railroad bridges of antiquated construction has been that, when such structures begin to fail in details, they sooner or later have to be taken out and replaced, in spite of all the patchwork that may be done on them.

Mr. Seaman asks for the details of the author's estimates, meaning probably the schedule prices adopted. The principal ones are as follows:

Metal erected and painted, 2½ cents per pound; vulcanized timber in place, $38 per M. ft. B. M.; rails with their details and fastenings in place, three 80-lb. rails per track, $1.80 per lineal foot per track; concrete, $7 per cubic yard; and excavation, including back-filling, 50 cents per cubic yard.

What metal is saved in Design 7 is required for end stiffeners and cover plates for cross girders as compared with Design 6, thus making the weight of metal per lineal foot the same for both designs.

Design 8 is lighter than either of these designs on account of the greater simplicity of the horizontal bracing resulting from the abutting of the outer longitudinal girders against the columns, notwithstanding the "cross girder strains and brackets," referred to by Mr. Seaman.

It would not be feasible in such a paper as this to give every detail of all the estimates made.

Answering Mr. Bouscaren's questions, the greatest variation in temperature was assumed to produce a variation in length of metal-work equal to 1 in. per 100 ft.; the wind load (or more strictly speaking the transverse horizontal load) assumed was 450 lbs. per lineal foot for the double-track structure, and 600 lbs. per lineal foot for the four-track structure; the speeds of trains assumed varied from 40 to 20 miles per hour according to the degree of the curvature; and all curves are compounded. The intensities of working stresses adopted in making the designs were as follows:

Flanges of longitudinal plate girders, extreme fibre, 8,000 lbs., allowing one-eighth of the web to act as a part of each flange; tension flanges of open-webbed, riveted longitudinal girders, 9,000 lbs.; compression flanges of same for combined bending and direct load, 9,000 lbs.; diagonals of same, from 6,000 to 8,000 lbs., according to the relative dimensions of angle legs; flanges of transverse girders, 9,000 lbs., allowing one-eighth of the web to act as a part of each flange; columns in compression only $12{,}000 - 45\frac{l}{r}$; columns for combined direct loads and bending of all kinds, including temperature effect, 20,000 lbs., where $l \div r$ does not exceed 45.

Mr. Horton points out that the author's elevation of base of rail is 21 ft., above the street. This applies only to the Loop, where various considerations necessitate a higher track level than that of the Northwestern, for which the height is from 18 to 19 ft. The height of the car floor was a fixed quantity, as it had to be made the same as on the other lines using the Loop.

Answering Mr. Mogensen's remarks concerning a solid floor, the author would state that the latter would not dispense with the use of timber ties, unless it involved great noise in operation; hence, Mr. Mogensen's first claim will not hold.

As an example of noisy operation in a structure where there is no timber cushion under the rails, the Park Avenue viaduct of the New York Central Railroad may be mentioned. On this structure the noise from a passing train sounds like that of an approaching tornado.

If Mr. Mogensen were to make a complete design for a structure with a solid floor that would be comparatively noiseless, he would probably find, as the author has found, that the extra cost would amount to much more than 15 per cent.

There was an error made in the preliminary edition of the paper in respect to the composition of granitoid, which has been corrected. Mr. Stuart's criticism, however, would now apply with still greater force, as the composition is less rich in cement than was stated. As it was Mr. Weston who specified and put in this granitoid, the author wrote him, sending a copy of Mr. Stuart's remarks, and has received the following in reply:

"Mr. Stuart's conclusions in respect to porosity of the mixture which we have used for the pedestal blocks on the Northwestern Elevated railroad are erroneous. The fact is that the texture of the finished stone is very compact and free from voids. The mixture, when properly manipulated, produces a stone which resists perfectly the action of frost.

> "We have on the Northwestern Elevated road several thousand pedestals made from this mixture. These pedestals have been during the past winter exposed to temperatures of 20 degrees below zero. I have only recently examined personally nearly every pedestal on the line, and I failed to find one among them which gave any evidence of deterioration.
>
> "As to the strength of the stones made from the mixture specified, they are superior in every respect to those made from the best limestones mixed with sand and cement mortar. Furthermore, it is the mixture in common use in Chicago for the best grades of cement sidewalks and continuous curb and gutter construction. Hundreds of such walks and gutters can be seen in perfect condition after having resisted the elements and extraordinary traffic for more than ten years."

The author must take issue with Mr. Trocon concerning the fixedness of column feet, for he is convinced that where four anchor bolts per pedestal are used on his Chicago work, the columns and pedestals are just as continuous as if the former were embedded in the latter to any depth.

The author agrees with Mr. Parsons in his preference for Design No. 8. It is the most satisfactory of all the double-track designs figured upon, but, unfortunately, it could not be used on the Chicago work, as all the double-track portion of the structure is located in the street, where a spacing of 17 ft. between centers of columns is inadmissible.

Mr. Connor expresses his regret that facing the end angles of the longitudinal girders was not called for in the author's specifications. The specifications contained this clause:

> "The ends of all webs that abut against other webs must be faced true and square or to exact bevel, and the end stiffeners must be placed perfectly flush with these planed ends, so as to afford proper bearing for the ends of the attaching girders."

In order to comply with these requirements the Union Bridge Company decided to make the end stiffeners ½ in. thick and to plane the ends of the girders after the stiffeners were riveted on, while the Elmira Bridge Company chose to plane the webs first and then put on ⅜-in. stiffeners to fit the planed webs exactly. The latter company, however, agreed to use thicker stiffeners and to rivet them on before planing, in case the inspectors reported the work to be unsatisfactory when done by the method last described. No complaint on this score has as yet been made, or, in truth, on account of any other matter concerning shopwork; and the author feels that he cannot speak too highly of the character of all the shopwork done thus far on his Chicago work by both the Union and Elmira Bridge Companies.

Mr. Hodge seems to think that the stating of correct principles of design for elevated railroads by the author is superfluous; but even to-day in designing structural metal-work these principles are more often honored in the breach than in the observance. As for "guessing" as to the number of extra rivets required for a connection, when the number required theoretically is small, the author maintains that two rivets do not make a proper connection except for lacing, and that when the number of rivets required by pure theory comes out almost exactly three or even four, it is better to add another rivet as a matter of precaution.

The author agrees with Mr. Weston that, all things considered, it would have been better to place the top flanges of the longitudinal girders a little above those of the cross girders instead of a little below. The result would certainly facilitate laying the track, but would require a little more metal and would involve a somewhat clumsy detail at the junction. On the connection of the Metropolitan Elevated to the Union Loop, which connection was designed by the author, such a detail was adopted at the request of the officers of the Metropolitan Company. In future work the author would not attempt to make the top flanges of consecutive longitudinal girders continuous or semi-continuous over the cross girders; but would cut them square off so as to clear the top flanges of the latter, upon which he would place pieces of steel buckled plate to receive the ties.

The author is glad to see Mr. Lindenthal's remark about the separation of incoming and outgoing passengers. If he could have his own way on this question, the author would make this a *sine qua non* in designing all stations for elevated railroads. The Northwestern stations, as he designed them, certainly provide for such a separation; and it is to be hoped that they will be built that way, although there is now some talk of abandoning the exit stairways.

Mr. Lindenthal has failed to recognize the fact that there will be no side view of the four-track portion of the Northwestern Elevated possible except at street crossings, and that consequently the difference in depths of longitudinal girders at the braced towers can never be noticed; therefore it would have been a needless piece of extravagance to make the webs of the short girders as deep as those of the long ones.

In respect to the question of æsthetics there seems to be such a variety of opinion that the author concluded to consult several architects of established national reputation and leave to them the settlement thereof. He, therefore, wrote to Mr. Henry Van Brunt, of the firm of Van Brunt & Howe, Kansas City, Mo.; Mr. Chas. A. Cummings, of Boston, Mass., and Messrs. Carrère & Hastings, of New York City, asking them for criticisms of his designs.

Mr. Van Brunt replied as follows:

"You have asked me for a frank architectural criticism of your proposition to decorate the construction of an elevated railroad, as illustrated in the last pages of your paper presented to the American Society of Civil Engineers, February 17th, 1897. The opportunity for the discussion of this difficult problem is so rare that I am disposed to avail myself of it seriously. The relations between our two professions are growing closer, and it is important that we should understand one another better.

"It has been observed that among semi-barbarous nations forms of art are developed from an instinctive conception of beauty, which has free expression because it is not embarrassed or sophisticated in its development by the knowledge of other forms of art indigenous to other people and resulting from other conditions of material and use. Thus, among civilized nations the accumulation and organization of knowledge, which to every other form of intellectual activity is a stimulus, seems to have proved, at least to some part of the art of the 19th century, a positive impediment. The cultivation of the mind through the knowledge of past achievements has in fact rendered the architect of to-day so self-conscious, and has supplied him with such a multiplicity of conflicting ideals, that his inherent creative power is weakened and his natural initial force is lost in a sort of intellectual timidity and vacillation. With the distractions furnished by his familiarity with history he cannot adjust himself to his own environment with the frankness and *naïveté* by which the masters of classic and mediæval times developed architectural style.

"In this respect the modern engineer enjoys a distinct advantage over his brother, the modern architect. Fortunately in the practice of his profession he is not embarrassed by these grave distinctions, and his art has consequently progressed with the general progress of the century. But when, in his bridge truss or his elevated railroad, he has evolved mathematically an economical structure, which commends itself to his own scientific judgment, and to the approval of those whose capital he is investing in a purely commercial undertaking, and finds at last that the results are an offence to the æsthetic instincts of mankind, the correction which he attempts to apply to satisfy this æsthetic instinct subjects him immediately to the very same embarrassments which beset the path of the architect. For almost invariably and inevitably this correction, as in the present case, is a reminiscence or tradition from an entirely different form of structure, and is applied too late in the process of construction to make good art. In fact, the correction is an afterthought; it is applied to a completed fabric, and forces it to assume an aspect which is not a harmonious development of its essential structure, but a concession to an arbitrary and conventional idea of beauty or grace.

"True architecture is construction carried to the highest point of development without the necessary addition of any elements foreign to its own conditions of stability and strength. Structure cannot be elevated into the domain of art merely by the application of ornaments. Ornament is contributory to a work of art and not essential to it. A Cistercian abbey has no ornament, but its rank as a work of art is as high as that of a Clunisian abbey which abounds in the richest decorative accessories. Certainly the true function of ornament is not to conceal or obscure construction, but to illustrate it.

"I very highly appreciate the motive which has prompted your attempt at decorated construction, and I recognize the ingenuity with which you have tried to solve this most difficult of all problems in design, but I beg to call your attention to the fact that this most praiseworthy effort would never have resulted as it has in your careful drawings if your mind had not been pre-occupied by the agreeable effect of the construction of a stone bridge. It is evident, however, that, executed, the phenomena of perspective would destroy this resemblance to this conventional type, and substitute some more or less unexpected and not entirely agreeable effects. It seems to me apparent, moreover, that the important arch form given to the longitudinal web is not an evolution from its essential structure, but is imposed upon it for the satisfaction of an ideal of grace; that the form of the brackets supporting the overhanging footway conceals, and certainly does not illustrate, the member which actually does the work; that the capitals and base moldings of the supporting piers are imposed upon a structure with which they have no sympathy, and are a reminiscence of forms invented for an entirely different material; and that the decorated entablature is merely a thin screen which does not suggest the structure which it masks, but recalls a structure of a very different sort, and is therefore with its moldings and panels simply a conventional and purely arbitrary symbol intended agreeably to beguile the spectator. You have done what a very large proportion of men in my own profession would have done, if called upon to make your completed construction more attractive to the eye, but all this decoration is applied and not inherent. It does not illustrate the essential and peculiar nature of the fabric and is not a part of it. Therefore, according to ethics of design, however agreeable and interesting to the eye, it is really a costly and ingenious deception and is not true art.

"If the structure without such masks is ungainly and uncompromising, the remedy to be sought for by the engineer should, it seems to me, be limited to bringing together the various members of a perfectly mathematical and economical construction with as much elegance of line and precision and finish of workmanship as he can possibly command. If he can use ornament, let him so use it as to illustrate the construction and not to conceal or weaken it. It is the misfortune of the engineer that he is dealing with a strictly mechanical problem, and is therefore constrained to use materials and methods which have as yet never been developed in the direction of that more perfect union which really constitutes the essential qualities of grace and beauty. I venture the proposition that, following the analogy of nature in the evolution of natural forms, no construction which is coarse or ugly can be perfect construction, and that the reasonable gratification of the educated eye must be the measure of such perfection.

"Centuries of experiment and study have been bestowed upon constructions in stone, baked clay, and wood, and certain ideals of beauty and fitness have been thereby developed suitable for such constructions. But the attempt to apply such ideals to constructions in iron or steel must result in error. The form which is beautiful and fit for the old materials will not necessarily be beautiful or fit for the new materials. Time and repeated experiments must determine the character of the new ideals by which we are to measure and judge the final perfection which apparently we have not yet reached in this department of human endeavor.

"We have all of us, architects and engineers alike, repeatedly committed the same faults which are evident in the interesting example which you represent. Therefore, the critic must present his strictures with becoming humility. I have simply stated the truth as I understand it, and I am very sure that your intelligence will receive it in good part."

Mr. Cummings' letter was as follows:

"I find the questions which you ask me rather difficult to answer categorically. I quite agree with you that as a rule the engineering structures which we are accustomed to see are unsightly and often hideous. I have in mind, at this moment, certain iron bridges in my own city, in prominent and most conspicuous positions, which are an offense to the eye and to the taste of thousands, so aggravated that I have often thought that every structure of the kind ought to be submitted to a competent commission for approval or rejection before being carried into execution.

"Certainly an elevated railroad is generally an extreme instance of deformity, and every attempt to ameliorate its ugliness deserves to be welcomed and commended.

"Yet, if I am to speak frankly of the design concerning which you have asked my opinion, I must say that I do not feel that you have treated the subject in the best way. Your design would certainly conceal the rough features of the iron construction—the girders, the **Z**-bars, the struts, the rivet heads and the like—but the concealment is effected by covering them with an imitation of the forms of an architectural construction in stone, of which the decoration is drawn from classic examples. It is here that I conceive you to be working on a wrong theory.

"I do not believe in borrowing architectural forms and applying them to the service of an engineering construction. I have never seen an instance where such an application seemed to me successful; and fortunately such a violation of the principles of decoration is not necessary. Every species of construction is capable of being made comely if not actually beautiful, without any concealment or denial of its materials or its methods. If the great engineering structures have so far failed to bear out this assertion, it is because the engineers in the first instance, and in the second those for whom their structures are designed, have not yet felt the importance of making them attractive to the eye.

"It would perhaps be asking too much of a profession whose work is of so strenuous and practical a cast as that of the engineer that he shall receive the training of an architect in design, but I think it not only entirely practicable, but entirely desirable and important that our schools of engineering should take some account of the possibility of so treating a problem of construction, whether of steel or stone, as to remove as far as may be done the reproach of ugliness and coarseness from the great structures which are one of the most conspicuous and most characteristic features of our later civilization."

Messrs. Carrère and Hastings wrote:

"We beg to acknowledge the receipt of your letter of April 20th, with which you sent us extracts from a discussion on a paper which you read, treating of elevated railroads, and in which you ask for an expression of opinion.

"We feel very much complimented at being asked to advise you in this matter, treating, as it does, a subject which has always interested us very much.

"In general, engineering works do not aim at beauty, and we think that this is always a great misfortune—whether the work be important, as in the case of a municipal bridge, or whether it be trifling, as in the case of small railroad bridges. Any engineering work is a spot in the landscape, or in the city, which has either a good or bad influence on the general appearance of the panorama, and upon its enjoyment.

"The fact that the first aim of every work of engineering is practical, that the essential qualities are strength, simplicity, and economy of cost and of operation, lead many very able engineers to the conclusion that they fail in these qualities in the degree in which they may be artistic; and for this reason many of them are not only indifferent, but are opposed to having their work beautiful. This is probably due to a misapprehension on their part of the elements required to make such a work beautiful, and perhaps, also, to the fact that the usual way of attempting this solution is so often irrational, and seldom, if ever, successful.

"It is, of course, a very desirable thing to consult a skilled architect as to matters of detail, such as ornamentation, the railing of a bridge, candelabra and other small details, which, if successfully designed, may add to the general interest of the bridge; but no amount of ornamentation can possibly add artistic interest to an engineering work unless the conception itself is artistic. In fact, ornament should be used very sparingly, and in an entirely subordinate manner.

"We believe that the great difficulty is due to the fact that engineers, not having been trained in matters of art, do not conceive or plan their structures artistically. They should seek the advice of the skilled architect at the very start, so that the entire work may be designed and constructed on artistic lines, which may even make the use of ornament absolutely unnecessary, or may make it of so little importance that it may be almost bad, and the structure still be beautiful.

"An iron structure, be it bridge, elevated railway or other, must be perfectly simple and rational in its construction; the material must always be used so as to express its individual character, and not try, either in its arrangement, proportions, or details, to assume to represent the use, proportions, or forms of another material; the columns should be only as big as necessary to carry the weight; the beams or girders only as big as necessary for the spans; and the ornamentation should be so designed as to be characteristic of the material and of the process through which it is obtained, whether cast, wrought or otherwise.

"In the case of an elevated railway, the conception is inartistic, as well as irrational. There is no logical or artistic reason for encumbering a street or avenue, or other highway, with a purely utilitarian structure such as an elevated railway. It destroys the outlook and the light, and in every possible way the enjoyment of the street or abutting property, as also the original purpose of the street; and it has no *raison d'être*, excepting either the rapacity of the corporation which occupies the street in preference to buying its right of way, or perhaps the necessity for having it there as the lesser of two evils, whether ugly or not, where the right of way is not otherwise obtainable.

"The thing, therefore, that makes an elevated railway inartistic is the very conception of the idea, and not the execution of it. We do not believe that it would be judicious to have, as it were, a structure decorated throughout; but whatever is done to make an elevated railway more sightly will have to be accomplished by designing it in the simplest and most straightforward way, so that the purely utilitarian portion of it will seem as natural, simple and graceful as possible, and in contrast to the purely utilitarian mass of the structure, by devoting some attention to the frequently occurring stations, and, where possible, by breaking the monotony by an artistic treatment, such as a viaduct, or the introduction of masonry or other features which may lend interest to these particular spots.

"We sincerely hope that you will succeed in convincing your fellow engineers that they have just as much need of the co-operation of the skilled architect in all of their work of this character, as has the skilled architect of the co-operation of the engineer in his work. As both works, that of the engineer and that of the architect, partake both of the useful, the true and the beautiful, it seems indispensable that there should be co-operation between the architect and the engineer and between the engineer and the architect, as the case may be."

As the opinions of the three architectural authorities referred to are entirely in accord on the question submitted, there is nothing for the author to do but acquiesce gracefully in their decision and acknowledge that his design for "an elevated railroad for a large city where expense is no object and where appearance is the great desideratum" is not a success, but a violation of true art.

Far, however, from regretting that he introduced the design as a conclusion to his paper, the author is very glad indeed that he thought of so doing, for the reason that the remarks of the architectural authorities just quoted may have the effect of inducing engineers engaged in the designing of structural metal-work to pay in future more attention to the important question of architectural effect in their constructions.

The author desires to express here his hearty thanks to Messrs. Van Brunt, Cummings, and Carrère and Hastings for their courtesy in complying with his request to decide this question of æsthetics.

As Mr. Van Brunt points out, steel construction is a modern innovation, and consequently no attention worth mentioning has yet been paid to the development of artistic features in its designing, for engineers have been influenced mainly by utilitarian and economic motives. If the old ideals of grace and beauty that pertain to constructions in wood and stone are inapplicable to steel, it is now in order to establish new ideals that will apply thereto; and, as engineers in general have been too devoted to utility and economy to train themselves in the artistic, it would be eminently proper for some architect who is posted in the designing of metal-work and cognizant of the fundamental principles which guide the structural engineer in his designs, and who is an authority upon æsthetics in his own line of construction, to make a special study of the subject of the architectural features of steel bridges, viaducts, and elevated railroads, then write for the American Society of Civil Engineers an exhaustive paper upon it, from which and from the subsequent discussions could be established principles governing from an artistic point of view the designing of all classes of steel structures.

In bringing this *résumé* to a close, it is proper for the author to point out in what particulars he would change his plans and specifications for the Chicago elevated railroads in view of the criticisms made in the discussions, were they to be redrawn.

First.—He would reduce the ultimate strength for basic medium steel 2,000 or perhaps even 3,000 pounds.

Second.—He would use carbon primer as the first coat of paint, and would endeavor to have it applied at the mills before the metal could be exposed to the weather.

Third.—He would consider very carefully and thoroughly the question of the advisability of omitting on tangents either the outer or the inner guard rails.

Fourth.—He would raise the top flanges of the longitudinal girders about 4 ins. above those of the cross girders, and block up on the latter with buckled plates to receive the ties.

APPENDIX.—DATA RELATING TO VULCANIZED TIMBER.

"NEW YORK April 4th, 1895.

"*Editor Railway World:*

"DEAR SIR,—A year or so ago much attention was given by railway journals, people who have to do with maintenance of way, and inventors, to the matter of ties for the road-bed. Columns in papers and many pamphlets were filled with articles on metal and glass ties. Little or no attention was bestowed on the plain every-day timber which has always been with us.

"Recently nothing has been said of would-be substitute ties. Is this caused by the failure of the experiments with the substitutes, or is it that better results have been obtained from the timber?

"I am inclined to the latter belief, and in support of the same offer the experience we have had with track timber on the Manhattan elevated system in New York City.

"When constructed, the elevated roads were equipped with 5-in. x 6-in. x 8-ft. yellow pine ties planed on all sides. The timber was of the best quality obtainable. It was not long before we discovered the ties suffering from decay. To the surface railroad man this may appear strange, considering that our ties are laid on iron girders. We have, however, many peculiar conditions to confront, and the cost of tie renewals was a very serious item of expense.

"To find a remedy for this and reduce what was beginning to be an immense maintenance-of-way charge, many preservative processes were tried, but none seemed to do the work until vulcanizing the timber was used. This process was first tried ten years ago, when we put in two sections of 6-in. x 8-in. x 8-ft. ties; one section of vulcanized timber and the other section of untreated material. It was not a great while until decay began on the untreated ties, while those vulcanized are still in service as good as when first laid. . . .

"Respectfully yours,

"(Signed) R. BLACK, *Roadmaster.*"

The following are extracts from a report which is certified to by the same Mr. Black:

"Agreeable to appointment, Messrs. F. Holbein, F. M. Grumbacher and Daniel Meyers met Mr. R. Black, roadmaster of the Manhattan Railway, at his headquarters at South Ferry station, on May 3d, at 1 o'clock.

"Mr. Black, who has been with the road since 1869, called attention to half a tie, not vulcanized, that had been in use five years. That portion of the tie where the rail had laid, and where iron bolts had been used, was very badly decayed, but the space between the rails showed no signs of decay. Mr. Black stated that vulcanized wood was not in the least affected by contact with the rail or bolts or metal surface, but that it seems proof against indentation by wear and friction, or pounding of the rail.

"The party was then conducted over the line of the Third Avenue Elevated, in order to be shown a comparison between vulcanized and unvulcanized wood in actual use on the structure. The first stop was at Chatham Square Station, where special attention was called to the condition of the natural yellow pine laid in 1886 on both City Hall and South Ferry branches. It was very much decayed and some portions so soft that it could be pierced with the end of an umbrella. It was a very rainy day and the timber was thoroughly soaked. This timber, Mr. Black remarked, was being replaced as rapidly as possible with vulcanized wood.

"Our second stop was at the Grand Street station, where vulcanized ties and guard rails laid in 1883 were examined. This vulcanized timber was found in as sound condition as when first laid. Mr. Black called attention especially to guard rails which he had bolted together in 1883, the inside rail vulcanized and the outside rail not vulcanized, in order to have both subject to precisely the same conditions in every particular, and to afford opportunity for comparison in later years. The vulcanized was as sound as when laid. The part not vulcanized was in a decayed, punky condition. Attention was called to the vulcanized flooring on the station platform. He stated that they formerly used tongued and grooved lumber, but now they used vulcanized slatting without tongue or groove, as it kept its place without warping or shrinking, although exposed to cold, rain and sun.

"The next examination was at One Hundred and Sixteenth Street. Ties not vulcanized, which were laid five years ago, were all being removed because of their decayed condition, and were being replaced by vulcanized ties."

* * * * * * * * * *

"Mr. Black stated that about four and one-half miles of creosoted ties were now in use on the suburban branch and called attention to the soft, spongy character of creosoted wood, that the iron plates supporting the ties were deeply embedded in the wood, and that it was difficult to keep the spikes in place, especially on curves. Extra appliances had been used to keep the rail in place. He also stated that during the hot season, when the temperature changed during the day from 40 degrees to 95 degrees Fahrenheit, causing expansion of the rail, spikes near the center of the rail would be lifted out of place from creosoted ties. He also stated that these ties were of yellow pine and the very best quality of creosoting, but that their experience was such that no more creosoted timber would be used, as vulcanized timber gave much better satisfaction; besides it does not affect the hands and faces of the workmen who handle it as creosoted timber does."

The following is a copy of a letter directed to Colonel S. E. Haskin, under date of March 1st, 1889:

"In replying to your enquiries as to the life of the cross-ties and planking which has been treated by the vulcanizing process, which we placed on the structure six years ago this month, I have to say, timber is sound and the surface of the ties and planking very hard.

"There are no indications of decay at the end of those planks which were vulcanized, while the planks not treated and placed on the structure about the same time are decayed at the ends, or where they are nailed to the supporting timbers.

"I am inclined to think the process of vulcanizing will soon be found to be the best way of preserving timber.

"Very respectfully yours,

"(Signed) ROB'T I. SLOAN, *Chief Engineer.*"

The following is a copy of a letter to the Haskin Wood Vulcanizing Company, under date of March 28th, 1891:

"In replying to your enquiry regarding my opinion upon your process of vulcanizing for the purpose of preserving wood from decay, etc., and especially with reference to the yellow pine railroad ties, which were treated by your company's process, and laid in the tracks of the switch-yard of this company in the spring of 1884, having been in constant use and exposed to the full action of the elements, and subjected to extraordinary wear and tear, I have to say that, on the 6th day of March, 1891, I had two of said ties taken up for the purpose of making an examination of their condition, and was much surprised to find them in a perfect state of preservation, and practically as good as new ties, so far as wear was concerned, the spikes having held firmly, as they were originally driven.

"During my experience in the railroad business of over forty years, during which time I have used all kinds of timber in railroad work, and have tried the various kinds of treatment for the preservation of timber from decay, I am free to state that I have never found any method that has shown such a satisfactory result; and I believe your process of vulcanizing will increase the durability of timber at least 50 per cent.

"The remaining ties, which were treated by your company's process, are in the same place as they were first laid, and from present indications they seem good for seven years' more service.

"In conclusion, I would say that I think it would be to the interest of any company using timber, which is exposed to the elements, to at least give this process a trial, as they could not fail to be convinced of its effectiveness.

Yours respectfully,

"(Signed) ROB'T WHITE, *Supervisor of Tracks and Repairs.*"

Mr. White wrote also to the same parties, under date of April 6th, 1891; as follows:

"Replying to your question as to the life of yellow pine ties, will say that, when used in the switchyard of this company, in their natural state, and exposed to the full action of the elements, they last, on an average, three years, during which time they have to be turned.

"The ties treated by your company's process of vulcanizing, and which were laid in the tracks of this yard in the spring of 1884, are perfectly sound, and have not been turned or respiked since they were laid."

The following is the *résumé* of a report to Colonel Samuel E. Haskin, under date of November 26th, 1894, by Mr. Alfred P. Trautwein, who had made a series of comparative tests on vulcanized and untreated yellow pine timber on the testing machine of the Stevens Institute, Hoboken:

"These experiments show the following average results:

"Modulus of rupture:	Untreated wood..........	10,762
" "	Vulcanized "	13,098
" elasticity:	Untreated "	877,098
" "	Vulcanized "	1,054,941

"These experiments, of course, were not numerous enough to determine exactly how much vulcanizing affects the wood, but they establish the general fact that so far from weakening the wood, the process of 'vulcanizing' seems to strengthen it; the modulus of rupture by transverse stress being 21 per cent. higher. The crushing strength was increased 23 per cent."

The author has been informed that the Hon. B. F. Tracy, ex-Secretary of the Navy, with a view of adopting vulcanized wood in naval construction, appointed a special committee which visited the vulcanizing works in New York, and, after an exhaustive investigation, reported that vulcanizing increases the strength and durability of timber, and recommended that vulcanized yellow pine be used for backing in one of the monitors. Their tests showed that vulcanizing increases the strength of yellow pine 18 per cent., and decreases the deflection over 13 per cent.

The following is a copy of a report to Mr. A. Bevier, General Manager New York Wood Vulcanizing Company, by J. A. Deghuee, Ph. D., Chief Chemist of the Pure Food Department of New York City, under date of January 29th, 1897:

"As to the result of the various tests made of your vulcanizing process; in order to condense it I will confine it to samples A and X. This will show you all the practical conditions of the changes brought about by your process.

"The piece of wood A was just twice the size originally of the piece I returned to you. The other half was cut up into fine shavings and the extractive matter dissolved out by cold ether, the contents being in bottle A. This piece of wood had been vulcanized by your process.

"Block marked X, untreated yellow pine, was also cut up and the extractive matter dissolved out by cold ether, contents being in bottle marked X. This block was also twice the size originally of the piece returned to you.

"The vulcanized extract in bottle A shows a mixture of resinous acids, together with a number of bodies similar to those in wood tar creosote, all of which have strongly antiseptic properties.

"By your process nothing escapes but the free water. The amount that can be extracted from the wood will vary in keeping with the character of it, *i. e.*, from a rich, resinous wood more can be extracted than from a lean porous wood. You will extract as much from vulcanized wood as can be extracted from untreated wood, nothing escaping in the process except water, and the amount will vary with the original condition of the wood. I do not believe that the strength of the wood is impaired in the least by your treatment; but on the contrary, the diffusion of the resins and other liquefiable matters throughout the wood, thereby adhering to the fiber, would have a tendency to solidify the contents and increase the strength. However, this is a mechanical question which can be determined by tests at Columbia College and Stevens Institute, where they have apparatus for making such tests.

"Besides the changing of the extractive matters into an antiseptic, you also coagulate the albumen, which has a tendency to seal up the pores.

"There is another benefit by your process which I think equally as important as the creating of an antiseptic and the coagulation of the albumen, and that is sterilizing the wood; and there is no doubt in my mind that from the amount of heat used, this is thoroughly done. In all wood there is living matter carried throughout it by the flow of sap; either living matter or spores which produce the same. This hatching, as you may term it, is brought about by heat and moisture and develops the spores into mould which eats the wood and produces what is known as dry rot. Decay is due to living matter and in order to produce decay in your process, the living matter will have to enter from the outside.

"By the creosoting process in some cases resin is mixed with the creosote to prevent solubility, and by your process I consider that you are accomplishing the same result. Your process also produces the same results to the very heart of the wood as are produced upon the surface. If the timber was of the quality of sample A, in my opinion you would create from 190 to 200 lbs. of antiseptic matter to a thousand feet board measure. I arrive at this conclusion from your statement that the average weight of yellow pine, such as sample A, is about 4,000 lbs. to a thousand feet board measure. The condition of the wood in your treatment would not be changed by the separating or splitting of the timber, as the treatment goes throughout, thereby leaving no exposed surface."

The author regrets the necessity for occupying so much of his *résumé* with testimonials as to the merits of vulcanized timber; but, as Mr. Belknap has asked for such data and tests, he cannot well avoid giving them.

COMMENT.

Ever since wrought iron and steel began to be used in engineering structures, the metal-work for railway bridges has been better designed and more carefully fabricated than that for buildings. Bridges carry moving loads which produce indeterminate, dynamic effects, vibration, and wear, while buildings commonly support statically applied loads that are much less in amount than those for which the sections were calculated. These facts have influenced engineers, often to an unwarranted degree, to strain the metal higher, to adopt cheaper and less satisfactory details, and to require a much lower grade of workmanship for buildings than for bridges. Bolts are very commonly employed where the use of rivets would be more advisable, rigidity is sacrificed, and secondary stresses are ignored in buildings by engineers who would not for a moment accept anything less than the best design and construction in bridges. Grave errors have been made and are being made to-day by scientifically trained and generally competent engineers, because they look upon the unscientific and often irrational methods of the ordinary builder, who is actuated solely by the desire for profits, as the established practice of the engineering profession. Good luck, force of habit, and the grace of God are often more responsible for the continuance of a building in service than the skill and care of the designer and the thoroughness of the constructor. This practice in the construction of buildings is all wrong, but there is some hope that it will eventually be corrected. A disaster like that which befell the Darlington Hotel in New York startles the public and the city authorities, and builders become more careful in consequence; but the sound, scientific discussion of the principles of building design to be found in the paper Mr. C. C. Schneider recently presented to the American Society of Civil Engineers and in the comments upon it, promises infinitely more beneficial results. If engineers, architects, and builders generally are brought to realize fully the faults in the present methods by Mr. Schneider's opinions and those of the engineers who discuss his paper, only the most foolhardy or conscienceless constructors will dare to continue to violate the first principles of design.

Similarly, Dr. Waddell's paper and the discussions upon it have undoubtedly modified the design and construction of elevated railroads. As mentioned above, the difference in the mode of application of loads on railway bridges and those on buildings in some measure accounts for the difference in methods of design and construction, but the grossly inferior designs of elevated railroads as compared with those of standard steam railway viaducts and bridges of the same period cannot be accounted for in a similar manner; for not only are loads dynamically applied to the elevated railway structure, but they are applied with much greater frequency than in the case of the standard railway. That the standards of design for the early elevated railroads were far inferior to those for steam railways there can be no doubt; Dr. Waddell pointed out the faults in his paper and the discussions confirm his statements. These older elevated structures remain in service and their defects cannot be hidden, for they grow more apparent as time passes. Gangs of men may be seen any day on the older New York lines, replacing rivets and adding braces or reinforcing plates to strengthen the faulty details. It is true that the railway bridges with which these structures should be compared are largely removed and replaced, but it must not be forgotten that the loads on the railways have been more than doubled while those on the elevated railroads have been increased very slightly, if at all.

A large part of the discussion of Dr. Waddell's paper turns upon the amount and action of the thrust from braked trains. The amount of this force varies with the condition of the track. If the rails are dry and free from grease the friction developed when the brakes are first applied will undoubtedly approach very closely twenty per cent. of the load, but the ratio decreases rapidly as the rails become wet or greasy. The editor used the dynamometer not long since to determine the tractive effort of an electric locomotive and found it to be as much as twenty-two per cent. of the load on good track and to average about eighteen per cent. on track in ordinary condition. There can be no doubt that the thrust which must be cared for will amount to from eighteen to twenty per cent. of the load under normal conditions; the only question to be considered is the method of carrying this load to the ground.

One commentator states that it is all absorbed by the floor. This recalls the argument of the contractor for a bridge company who was endeavoring to obtain the order for a mill building on a design prepared by his company. Competition was close; hence, though bracing had been provided in the roof, the rigidity of the siding had been relied upon to transfer the wind stresses to the ground. The intending purchaser inquired what became of the wind stresses and was informed that the bracing in the roof carried them to the ends of the trusses and that they were then "dissipated along the eaves."

Many of those who discussed the paper argued that it is unnecessary to design the bracing and columns to carry the longitudinal thrust to the ground and that the floor would distribute it over so many columns that the bending in each might be safely neglected. Such a method of caring for the thrust is directly opposed to the conservative, scientific customs of the bridge designer. The floor is far from a reliable medium for the transmission of heavy stresses. The rail joints are made loose in order to provide for the expansion and contraction of the rails due to changes in temperature; and the joints in the guard rails or the attachment of the floor to the longitudinal girders must provide for the difference between the expansion of the stringers and that of the guard timbers. The frictional resistance of the joints is considerable, hence the floor will undoubtedly transmit appreciable stresses, but who shall say for how much it may be depended upon? And suppose the thrust is distributed over a large number of columns; the stress on each is reduced in amount, but it must be provided for none the less, or large vibrations will be induced.

Several commentators argued that the thrust of braked trains does not set up vibrations, but Mr. William Barclay Parsons' careful measurements with the transit were not needed to refute this. If any one will stand on the platform of a New York elevated railway station as the train approaches, no further evidence will be required to convince him that the vibrations are so violent that all connections between the longitudinal and the cross girders and between the cross girders and the posts must be subjected to violent stresses and wear.

Many engineers advanced the arguments that vibrations do no damage and that it is more economical and satisfactory to construct a more flexible, resilient structure than one designed to carry the stresses to the ground by the most direct route. Mr. Pegram especially advanced this argument and pointed to a structure of his designing, an elevated railway in Kansas City, as an example of the best type of such structures, predicting that it would give long and satisfactory service. The trusses are illustrated in Mr. Pegram's discussion. Unfortunately for the arguments in favor of the flexible structure, the longitudinal girders in this railway have worn so badly that they are now being removed and replaced. The structure has vibrated so much that the eye-bars have worn grooves in the pins as much as one-quarter of an inch in depth. The railroad has carried loads little if any heavier than those for which it was designed, yet its life was only eighteen years. This record is even worse than that of the old New York railroads.

One of the most evident distinctions between the work of the civil engineer and that of the mechanical engineer is to be found in the facility with which the character of a design may be determined. A few months at most is sufficient to settle whether a machine is economical to operate and to maintain; in fact, a very good idea of its probable life is easily gained; but it requires many years to determine the life of a railway structure. Even to establish the cost of maintenance is a matter of several years, hence the comparative value of good and bad design and workmanship in an elevated railroad long remains a matter of judgment only.

The New York and Brooklyn elevated railroads continue in service, notwithstanding their many faulty details, but the cost of maintenance is undoubtedly very great. The figures are not available, but even the casual observer cannot fail to notice how constantly repairs are being made, rivets are being replaced, braces and gusset plates are being added, and the webs and flanges of girders are being strengthened at all times. In the course of time the cost of repairs will increase so that it will be more economical to replace the present structures with others of modern design than to continue to maintain the old metal-work.

The great majority of the well-versed bridge engineers of to-day will undoubtedly agree that rigidity is the prime essential to a satisfactory elevated railroad; but the means for obtaining it must be governed by the conditions under which the road is to be built and by the judgment of the engineer. No general rules can be established except the almost self-evident one that the thrusts must be carried to the ground by the most direct route possible, and without overstraining any of the metal. To fix the lower end of the columns undoubtedly adds to the rigidity of the structure; for it enables the superstructure and the foundations to act as a unit and thus increases the mass available for the resistance to vibration.

The anchorage and pedestals proposed and used by Dr. Waddell have proved to be quite adequate even in the treacherous sub-soils of Chicago. In the comment upon his paper several engineers criticised the length of the anchor bolts and argued that they should extend to the bottom of the pedestal, if the end of the column be considered fixed. That the criticism is ill-founded goes without saying; for the cohesion of the concrete will cause the pedestal to act as a unit, and it is well known that the adhesion of the concrete to the metal will develop the full strength of a very short stone bolt which is not provided with a washer at its lower end, consequently the anchor bolts used are ample in length.

The methods of manufacture and the chemical and physical properties of structural steel received very careful attention, both in Dr. Waddell's paper and in the discussions, Mr. Cunningham's comments being especially noteworthy. The art of steel making was well understood seven years ago, but material advancement has since been made. The hard spots and lack of uniformity in medium steel have been overcome, and that grade of metal is now quite as reliable as soft steel. The manufacturers incessantly urge the use of soft steel; and many engineers employ it because it is soft and easily fabricated and, consequently, is less liable to incipient cracks from punching and shearing. It is argued that, since the damage in working is small, all holes in soft steel may be punched full size, thus saving material expense in fabrication, while the greater hardness of medium steel renders such treatment of it unsafe. When the shop work is done with sufficient accuracy the argument is good, but only shops which are equipped with the most modern tools and whose men are well trained and are habitually accurate can do the best grade of railway bridge work without sub-punching and reaming. Where the modern multiple punch with a well designed spacing table is used, the holes are punched with the greatest accuracy; but even then flange angles for girders are punched in both legs and stretch more than the web plates to which they are attached and, consequently, the rivet holes do not match perfectly.

Shops which pay their workmen by the piece are liable to produce less accurate work than those which pay by the day, for when a man's wages are dependent upon the number of holes he punches, accuracy will be subordinated to speed. Where the piece-work system is employed fines are exacted for inaccurate work; then the degree of accuracy depends upon the amount and rigor of the inspection, which is commonly regulated by the vigilance of the purchaser's rather than the shop's inspectors. There are many shops which do careful, honest work; but there are many others which will sacrifice quality for cheapness; and, since the consulting engineer rarely knows which contractor will obtain the contract, he must keep the most unfavorable conditions in view when drawing his specifications.

The quality of the finished product, however, depends almost, if not quite, as much upon the character of the riveting as it does upon the matching of the holes. If the holes are sufficiently well matched to permit the hot rivet to be inserted without drifting, if the rivet is hot when it is driven, and if the machine has ample power, slight irregularities in the matching of the holes are of no consequence, for the metal in the rivet will flow freely and fill the hole perfectly. But bad practices often prevail in riveting as well as in punching. If the riveting machine has not sufficient power or if the rivets are too cold the metal will not flow freely and the hole will not be filled, though, on account of the friction under its heads, the rivet may appear to be tight. It is not uncommon to see a number of rivets driven when they are at a blue heat, because, after they have been inserted, the progress of the machine has been delayed until they have cooled. Under the piecework system such rivets will never be replaced by hot ones before driving unless the inspector is unusually vigilant. But with first-class punching and riveting soft steel may be fabricated in a thoroughly satisfactory manner. The purchaser runs grave risk of getting less than the best of work, however, unless he restricts the bidding to shops of good reputation and employs competent and faithful inspectors.

How much more the perfect joint obtained by drilling or by sub-punching and reaming the rivet holes after the parts are assembled may be strained has not been satisfactorily determined. The Watertown arsenal tests mentioned by Mr. Rouscaren in his comment indicated that the perfect joint thus made is worth fifteen per cent. more than the ordinary joint in which the holes are punched full size, but the tests are inadequate and the data too meagre to warrant the acceptance of such results as final. The editor does not believe that a rivet driven in sub-punched and reamed holes is worth any more than a rivet which is properly driven in holes which have been punched with sufficient accuracy to permit the insertion of the rivet without drifting. But it must be accepted substantially without argument that sub-punching and reaming insure a higher quality of work than can be obtained when the holes are punched full size, unless unusual care be taken. Consequently, if medium steel can legitimately be strained so much higher than soft steel that the saving in metal will offset the cost of sub-punching and reaming, the most satisfactory results will undoubtedly be obtained by adopting this practice. The cost per pound of the base material is the same for medium as for soft steel; but the pound price of shop work and erection must be greater for the former than for the latter, since the weight is less and the amount of work remains substantially unchanged, if the reaming be excepted. Consequently, the additional pound price of reamed medium steel over that of punched soft steel is composed of two items, the cost of the reaming and the proportionately higher cost per pound of the other work on the lighter medium steel.

Whatever the origin of the higher pound price of the reamed medium steel, to satisfy the demands of economy the more expensive metal must be strained so high that the total cost of the completed structure will be no greater than if the lower priced soft steel had been used. Higher unit stresses for reamed medium steel are justified by the greater strength of the base material, the smaller damage in fabrication, and the greater average value of rivets driven in reamed holes; but how much higher stresses may be used is largely a matter of the engineer's judgment. The latest Manufacturers' Standard Specifications call for three grades of steel, viz., rivet, railway bridge, and medium. The railway bridge is commonly known as soft steel; and its ultimate strength varies from 55,000 to 65,000 pounds per square inch in tension. The medium steel varies from 60,000 to 70,000 pounds per square inch in tension. Apparently the average ultimate strength of the former is 5,000 pounds per square inch less than that of the latter; but it will be noted that steel whose ultimate strength varies from 60,000 to 65,000 pounds may be classified as railway bridge steel or as medium steel, according to the convenience and wishes of the manufacturer. As a matter of fact, the manufacturer endeavors to produce metal which will satisfy either specification and a range of 5,000 pounds in the ultimate strength permits him to accomplish his purpose quite commonly. When the strength of a melt is high it is classed as medium steel, and when it is low the material is railway bridge steel, but the bulk of the steel rolled may be either. Hence it is manifest that the engineer is generally employing one grade of steel, however it be named, unless he have material rolled to very unusual specifications. Consequently, it would appear that under ordinary conditions the adoption of higher unit stresses for reamed medium steel can be justified only on the ground that the superior workmanship increases the strength of the completed structure and provides greater security against failure due to harsh treatment of the metal during fabrication. In the absence of satisfactory tests, and thoroughly satisfactory tests would be very difficult to make, whether the superior workmanship certainly secured by sub-punching and reaming justifies the higher unit stresses necessary to offset the cost of reaming is purely a matter for the engineer's judgment.

After the introduction of steel for bridges and buildings it required many years for the manufacturer to perfect his processes so that he could produce uniform and reliable materials and for the engineers to overcome their prejudices in favor of wrought iron and to establish the safe and satisfactory unit stresses for various conditions of loading. In fact these objects are hardly more than accomplished now, when the advent of cheap nickel promises to introduce a new alloy which will supplant carbon steel for many purposes and for which new values will have to be determined. Nickel steel is already in use for a variety of special purposes such as boiler tubes and forgings; and prominent engineers have already advised its use for large and important bridges. Some time since Messrs. Waddell and Hedrick were retained by the leading producer of nickel to make an elaborate investigation and extensive tests to determine the most satisfactory and economical nickel steel alloy and the advisability of using it in railway bridges of both ordinary and extraordinary spans. Considerable progress has been made, and it is expected that the results of the investigations and tests will become available during the current year. It is now anticipated that nickel steel will be so superior to carbon steel in strength that long span cantilever bridges in which it is employed will be more economical than suspension bridges.

The comparative value of basic and acid open-hearth steel so pertinent eight or ten years ago is no longer of moment; for the largest steel manufacturer in this country does not operate an acid open-hearth furnace, in fact there is but one manufacturer prepared to furnish acid open-hearth structural steel in commercial quantities.

Though but ten years have elapsed since the foundations for the Northwestern and the Union Loop Elevated Railroads were constructed, the materials commonly entering into the construction of concrete have been materially modified. It was noteworthy then that Portland instead of Rosendale cement was used, for Portland cement was expensive and nearly all of it was imported. American brands had been established but a short time and were not generally considered equal to the brands of foreign manufacture. Since, the use of Portland cement has become almost universal, its consumption has increased enormously, and substantially all that is used in this country is of American manufacture.

It has been discovered, too, that better concrete is obtained at less cost by using without screening all the stone that comes from the crusher. The percentage of voids is thus reduced and the strength of the concrete is increased.

Notwithstanding the enormous increase in the production and use of Portland cement its quality has not been greatly improved, and, except for the use of the screenings, the materials composing concrete and their proportions remain unchanged.

In the choice of paint the engineering profession is as much at sea as ever. There are many good paints on the market and there are bad ones without number. It is the general opinion that even the best of them vary in quality; and fresh investigations on the part of the engineer generally lead to the adoption of some other brand than the one he has been accustomed to use.

All paints fail in their purpose, however, if they are not properly applied. Structural steel is too commonly painted out doors, even in wet or freezing weather, and it remains the very general practice to apply the paint just before the material is shipped. Metal is very rarely cleaned thoroughly before it is painted, and much of it is well rusted in the stock yards of the mill or the shop before it is fabricated. The mills never remove the scale or take any precautions to prevent the material from rusting while it is in their possession, and the shops do not even store their stock under cover.

These bad practices are well established in our commercial methods of steel construction and no one or two or dozen engineers can uproot them. Competition is keen, and a great portion of the business is done without the aid of an engineer other than the one employed by the bridge company; a great many of the engineers retained by railways and other purchasers of steel accept the common practice without protest; consequently, upon the great bulk of the work there is no demand for improvement, and it is impossible for the few who appreciate the value of clean steel and good paint well applied to obtain what they desire. The mills make their profit by producing a large quantity and any treatment of the steel which would apply to only a small portion of the product would reduce the output; consequently, innovations are strenuously opposed, even though their value be well recognized. In a like manner the shops oppose any process which is not applicable to the principal portion of their product. Therefore no serious reform can be effected until a considerable percentage of buyers of structural steel become willing to pay for and demand the adoption of effective means of preserving the materials.

The treatment of timber for all important constructions is rapidly becoming a necessity, for the destruction of American forests is progressing and prices of lumber are increasing accordingly. The quality of Georgia yellow pine used on the Northwestern Elevated Railroad now costs about sixty per cent. more than it did eight years since, and other varieties of lumber are increasing in value at a similar rate. First-class white oak is very difficult to obtain at any price. The Department of Agriculture, Bureau of Forestry, is exerting the utmost effort to bring engineers and other users of lumber to a realization of the situation and to enlist their help to preserve the forests by treating timber so as to prolong its life. In Europe the cost of railway ties has risen till it is economical now to increase their period of service by expensive methods of treatment, and it will not be many years until similar conditions obtain here.

In the *résumé* of the discussions upon his paper, Dr. Waddell clearly proved the economy of treating the track timbers for the Chicago elevated railroads and showed that the New York roads had already found the treated timber the most economical when prices were much lower than they are now. No designer of future elevated railways can afford to use ties and guard rails in their natural state.

In the discussion relating to the best column section the bulb angle, a shape which has been used in the New York subway, was not mentioned because it was not then generally offered by the mills. Four bulb angles and a plate form an excellent column: the metal is well distributed; the exposed edges are formed by the bulbs and are, consequently, able to resist a heavy blow; and since but two lines of rivets are required, the column is economic in construction. It promises to be widely favored for light work.

The design of the stations on the Northwestern and Union Loop Elevated Railroads is distinctly in advance of anything to be found in New York. The separate exit stairways alone are of untold advantage, as any one can testify who has tried to go up or down the common stairway of a New York station when most of the travel is in the opposite direction. The use of the turnstile offers a serious impediment to the movement of passengers and is a source of annoyance when travel is heavy.

Dr. Waddell and his commentators have discussed in detail substantially every point of importance in relation to the design and construction of elevated railroads. The result is not complete agreement by any means, but Dr. Waddell succeeded in establishing firmly the essential principles of design, and no designer will in the future disregard them. There need be no fear that another expensive structure will be constructed on the old, unscientific lines. No engineer will care to assume that an elevated railroad is less important and should be less carefully designed than a railway bridge. To design a structure which is distinctly in advance of what has been done before is a substantial contribution to the science of civil engineering, but to place on record where they are available for general use the results of the careful and expensive studies upon which the design is based and to evoke the opinions and practices of other engineers so that they are also available, is an inestimably greater service to the profession.

THE BRIDGE ENGINEER.

BY

J. A. L. WADDELL, '75.

WRITTEN FOR

THE POLYTECHNIC.

INTRODUCTORY NOTES.

A sound education and a broad and thorough experience constitute the essential preparation for consulting practice in any branch of civil engineering, but after graduation the reading and work should, so far as possible, follow the line of the chosen specialty or its allied branches. The plan outlined by Dr. Waddell in his address to the students of the Rensselaer Polytechnic Institute upon the preparation for consulting work in bridge engineering is exceedingly comprehensive and should provide a sound knowledge of both the theory and the practice of bridge engineering and a working knowledge of the lines closely related to it. Railway construction is probably the most useful of these from the technical point of view, but the detailed knowledge of the fabrication and erection of bridges is the best practical experience mentioned.

There is one line of work, however, which Dr. Waddell has not included, but which should be of the highest value in establishing and conducting a consulting office, namely the contracting portion of a bridge company's business, or of any similar business in which engineering is an important factor. The responsibility for the prices, and, consequently, for the net earnings of the company, lies largely with the man in charge of the office, but the man who conducts the negotiations must, if successful, be able to obtain business, often in the face of a competitor's lower prices, on the merits of his company's responsibility, its engineering skill, or the superior quality of its workmanship. It requires skill, tact, and diplomacy of a high order to obtain better prices than your competitor demands for a product not manifestly superior to his. This is what a successful contracting engineer must do, and the skill which he must develop in order to do it is precisely what he will need to obtain work as a consulting engineer.

To obtain engagements is probably the most difficult portion of a consulting engineer's practice. He must sell his services, something intangible, of which the value is difficult to determine. The bridge company offers a completed structure for a given price in which the services of its engineers do not appear as an item, consequently, the short-sighted purchaser, and his name is legion, believes he is saving the engineer's fee by purchasing directly from the bridge company. He believes he is buying only the structure and his belief is hard to shake, though, as a matter of fact, he is paying for not only the design of his structure, but for that of several other structures for which the bridge company prepared designs but did not obtain the contract.

The experience in contracting is also of great value in extending the acquaintance, as it brings the engineer in contact with the purchaser of structures and with consulting engineers as well, and a broad acquaintance is one of the consulting engineer's most valuable assets. Hence, a year or two spent in the endeavor to obtain contracts should be added to the experience Dr. Waddell has prescribed for the consulting bridge engineer.

THE BRIDGE ENGINEER.

By J. A. L. Waddell, '75.

Written for the Polytechnic.

As the title of this paper has been chosen by the editors of the *Polytechnic*, the writer feels at liberty to take advantage of its vagueness by treating it from the point of view which seems to him most advisable and, under the circumstances, most appropriate. This method of treatment will consist of an exposition of what course it is best, in the writer's opinion, for a young man to adopt in order to fit himself to become a successful bridge engineer.

The first essential, as nearly every one nowadays will concede, is a full course of study in civil engineering at one of the leading technical schools of America; and even this course might be preceded with advantage by two or three years at college, provided that no time be wasted there in studying dead languages, mythology, and a lot of similar rubbish that used to be considered the principal and essential part of a gentleman's education.

As a rule, students in technical schools are not sufficiently educated before entering, and as they are taught there but little besides technical studies, they graduate lacking, not only a polished education, but oftentimes a respectable common one. Ample evidence of the truth of this statement is furnished by the correspondence and printed papers of alumni of technical institutions; for, in respect to style, spelling, and composition their authorship would often disgrace the average schoolboy.

Again, the preliminary education of the technical student should be broad and liberal, because technical education is essentially the reverse, confining the mind to a single channel, albeit a wide and excellent one.

It is not considered to be the province of the technical school to teach its students the English language; nevertheless much can be accomplished in this direction by a compulsory thesis in each subject taught, and by paying due attention to the diction and style as well as to the technical features of the papers submitted.

Then, too, scientific and literary societies among the students, encouraged and fostered by the faculty of the institution, do much toward ameliorating the essentially technical character of the course of study.

But let us suppose that the would-be engineer has not only a thorough, sound English education, but also has just completed his technical one by graduating at one of the leading engineering schools. What course is he to pursue, and what are to be the guiding principles of his professional career? Shall he, like most of his classmates, graduating with great notions of their own importance, look about him for the best paying position obtainable, and ever after be guided in the choice of work by the largeness of the compensation; or, on the contrary, shall he set aside for many years the question of financial recompense, contenting himself with earning but little more than a mere living, and devoting all his energies to the acquisition of knowledge that will in after years "bear fruit an hundred fold"? But few newly fledged engineers would have the courage to adopt the latter course, nevertheless it is the one which will eventually, in the writer's opinion, lead to the greatest success.

Naturally, one would think that if a young man desires to become a bridge engineer, the first step to take after graduating is to enter the office of some well known bridge specialist, or that of one of the leading bridge companies, and thereafter devote himself exclusively to the study of bridge building. No greater error than this could, however, be made; although it is true that such a course will generally lead to a certain modicum of success both professionally and financially.

An engineer, though, who could be content with earning a fair salary, but who does not care for the professional distinction that is to be obtained by earnest effort backed by good ability and sound judgment, is not an engineer of the ideal sort, although he may always do his work faithfully and well.

If all the members of the engineering profession were to work simply and solely for their own personal, pecuniary advancement, how much progress would the profession make?

Is it not to the writers of engineering papers and standard books more even than to builders of great engineering works that progress in the profession is due; and is not the writing of such papers and books in ninety-nine cases out of one hundred merely a labor of love? All the reward that usually comes to the technical writer is the reputation that he obtains; and very often good, solid work in writing is done, such as the accumulation and digestion of statistics, for which the author can hardly hope for any acknowledgment except, perhaps, from a very limited number of his professional brethren.

If we agree then that there should be a higher ambition for the young engineer than the making of a comfortable living or the accumulation of wealth, how will this conclusion affect the course that he ought to pursue?

Evidently it will do so by showing the necessity for an accumulation of knowledge and experience that will form a fund of information which, in after years, will constitute the principal part of his working capital. Moreover, this knowledge should be by no means in one line of investigation or in one branch of engineering; for all the various branches are so interdependent that he who has confined his researches to one specialty will be continually finding himself at a loss as to how to solve problems that confront him, but which are not in his direct line of work and thought.

If, therefore, the would-be bridge engineer wishes to pursue an ideal course of practice with a view to the future rather than to the present, let him for a number of years choose subordinate positions in various branches of engineering that are not too widely divergent from his future specialty. The most nearly allied branch being that of railroading, let him serve for a year or two on a corps of railway engineers, obtaining experience in preliminary, location, and construction; and, as he attends to his regular duties, let him pay special attention to every question relating to bridges that arises, keeping full and systematic notes for future reference.

This matter of keeping notes is a most important one, and is too often neglected. A diary as a record of work should be kept, as well as a more pretentious note book in which to record methods and facts that are not to be found in text books.

During these years of preliminary training the young engineer should by no means neglect his reading, but should make it his business to peruse the principal technical newspapers and periodicals, and to keep posted concerning what new engineering books are issued, purchasing such as his means will allow and his time will permit him to read. It is a good plan to carry at all times in the pocket some engineering book to read at odd moments, for instance, when waiting for a railway train, or during the noon hour when in the field; and the tendency of the reading should ever be towards the chosen specialty, although not devoted exclusively to it.

If a subordinate on a corps of railway engineers show that he is ever willing to aid others when not busy with his own special duties, and that he is always anxious to do extra work, he will be given many opportunities to obtain valuable experience. At the same time, it is true, he will find that the indolent members of the party will be only too glad of the opportunity to saddle their duties onto ready shoulders; and our friend may in consequence often find himself overworked; but he should then comfort himself with the reflection, that there is no royal road to success, and that the harder he works the more he learns and the fitter he becomes for his future career.

As soon as he finds that he has mastered thoroughly one set of duties, let him apply for some other kind; and as he has already shown himself to be an efficient and willing worker, his request will in all probability be granted, more especially as the question of increase of salary will not be raised. It is bad practice for a young engineer to be continually demanding an increase of salary; for if his employers fail to appreciate his services and to pay for them what they are worth, it will be much better for him to change employers. Let him bear in mind the fact that in this great country there is always employment to be had by a willing worker; and that no man need starve under any circumstances unless, perchance, he be lost in the bush, which accident, it is true, is liable to happen to railroad engineers.

As soon as our engineer finds that there is not much more in railway engineering that can be learned rapidly, it will be about time to make a change by taking up some other line of practice, for instance, municipal engineering. He can best obtain experience in this line by taking a position in the office of the city engineer of a large city. A few months, however, in this branch of engineering ought to suffice. His attention should be devoted principally to the study of pavements, street grades, and bridges. If at the same time he can pick up a little knowledge of sewerage and water supply, so much the better, though this is by no means essential.

Next it would be well to obtain a few months' experience in a foundry and machine shop, learning by observation, by reading the best standard works thereon, and by conversation with the moulders, pattern makers, and other employees, how castings are made and how to handle the principal tools.

Just here it is well to observe that an engineer can pick up many valuable points by talking with any intelligent and experienced workman; and that it is by no means *infra dig.* to accumulate knowledge in this way.

Everything of value learned should be recorded, even if one be blessed with an unusually good memory; because the work of a busy engineer is enough to ruin in a few years the best memory ever possessed by man.

Throughout his whole professional career, our engineer should make himself acquainted with the money values of engineering materials and work, not only for use in his future practice, but also for the purpose of making a favorable impression upon the parties who consult with him about various enterprises; because there is nothing that will give the average man greater confidence in an engineer than to see that he has a good general idea of the value of the work under discussion.

As soon as he is eligible for membership in the various grades of the American Society of Civil Engineers, our engineer should by all means enter them; and he should never fail to become acquainted with as many engineers of established reputation as possible, endeavoring in each case to create such a favorable impression that the acquaintance will not be forgotten.

If papers are under discussion by the Society, concerning which he deems that he holds opinions of value, let him take part in the written discussion, stating his opinions modestly but firmly, and defending them vigorously until, peradventure, he be proven in the wrong, in which case let him acknowledge his error gracefully. No one is thought any the less of by high-minded individuals for acknowledging an error.

As soon as our engineer feels that he has discovered something useful and hitherto unknown, or has accumulated valuable statistics, let him formulate his ideas and present them in the shape of a paper to some engineering society; but it is well not to begin writing too soon for fear of evolving something weak or valueless. It is much better not to be known at all as a writer than to be known as a poor one.

Should he be located for any length of time in a city where there is a local engineering society, by all means let him join it, attend all of its meetings, and take part in its discussions, reading a paper occasionally, should the opportunity offer.

After completing his experience in the foundry and machine shop, let him devote some six months or more of his time to the inspection and testing of material for bridges, in the employ of some large and well known firm of inspectors. During this time he should have the opportunity to learn much more than the mere inspection and testing of metals; for he could acquaint himself with the various styles of details of bridges, and learn how ironwork goes together in the shop, and how it is manipulated. He should make a special study of detailing with reference to simplicity and ease in construction. In the course of six months or a year he would probably have opportunities to inspect manufactured metal at several of the principal bridge shops of the country, and could therefore learn the best methods of putting ironwork through the shops with the least expense and delay. He should pay special attention to the loading of bridge members on cars, in order to be able in the future to specify how the metal for his own bridges shall be loaded.

Next, let him spend a year in the office of some bridge specialist, so as to learn correct methods of design, in which the factor of economy of metal will not occupy a too prominent place.

Next, let him serve as assistant computer for about a year in the office of one of the leading bridge companies, passing from there to the drafting room of the same company, where it would pay him to remain six months or a year longer.

During these two years he ought to be accumulating most valuable knowledge and notes; for, by means of friendly conversation with the various employees of the bridge company, he can obtain an insight into every department of the business.

Next, let him spend about six months on the erection of a large viaduct or elevated road, and when this is finished let him serve on the erection of a large bridge over some important river, starting in at the beginning and remaining until trains are crossing the structure. Here he would obtain experience on substructure as well as on superstructure, and would be able to learn the entire *modus operandi* of sinking piers by the pneumatic process, by open dredging, or by means of the coffer dam. During the preceding years he should have read all the literature of any value on substructure, so that when he takes hold of the work of putting down the piers he will be well posted on the theory if not also on the practice.

There is one important matter that he should not have neglected during all of these years of apprenticeship, viz., the collection and study of forms of specifications and contracts, with the idea in mind of improving on them in his future practice. Moreover, he should read and study the relations between engineering and law, so as to avoid legal complications when the time comes for him to manage and control great interests.

If, during the years thus spent, there have not occurred sufficient mathematical work in his practice to prevent him from becoming rusty in his mathematics, he should have occasionally read up thereon in some of his old text-books or in new ones, if any improved ones have been issued.

Some one may object to this schedule of work by stating that there is not time enough for it; but, if so, the writer begs to differ with him on the grounds of personal experience.

Some one else may say that the amount of work laid out is either enough to kill a man with an ordinary constitution, or else it is so great as to render one's life a burden by leaving no time for relaxation. To this the writer would reply that unless a young man be blessed with a good, sound constitution, it would be most inadvisable for him to choose engineering as a profession, and positive insanity for him to adopt the specialty of bridge engineering, if he have any intention of making his mark in it. But if a young man of sound constitution and good habits will follow out the course here indicated, at the same time paying due attention to his physical condition, he will find himself equal to the work.

It is about time now for our engineer to have a change, so let him obtain the position of assistant professor in one of the higher departments of some well-established technical school, with the intention of remaining there two years, but no more.

For the first year his time will be occupied almost exclusively in reviewing his old studies in order to teach his classes; and he will find that he never before got so thoroughly to the bottom of things as he does now; for in order to teach anything to others one must understand it fundamentally in every particular himself. There is no training in the course of an engineer's practice that will compare in effectiveness with that obtained in the class room, and in the preparation for teaching. Moreover, there is nothing that will tend to give a man more confidence in himself and in his own powers, than will the teaching of a class of bright, earnest students, who are always on the *qui vive* to catch the professor napping, and who are constantly pitting their mental powers against his.

For the first year of teaching our engineer will conclude that he never until now knew what is really meant by hard work. If he teach the higher branches of civil engineering, including applied mechanics, he will often after a séance of four hours find himself absolutely exhausted, both mentally and physically. But, strange to say, after the first year, all this will be changed. By that time he will have gone over the entire course so that in future his teaching will be an old story; and he will have attained such self-possession and confidence that he will with perfect equanimity permit himself to act as a target for class after class in their endeavor to floor him by asking questions.

If there were no other work now than teaching for our engineer, it would be time for him to send in his resignation; but there is plenty in addition to keep him occupied for another twelve months. In the first place, let him work up into papers the data that he has been accumulating for years; thus serving a double purpose by adding to the recorded knowledge of the profession and by bringing his name before the public.

In the second place, there is surely some subject that he has run across in his practical life which needs experiment and investigation, and what circumstances are so favorable for this as the environment of a professor at a good technical school?

In the third place, our engineer may have so developed his self-confidence as to have the audacity to write a technical book. This would be the only legitimate reason for his remaining a third year as instructor.

These years at a technical school will give him an opportunity to consider as to choice of locality for opening an office; because during vacations he can travel and look about him.

If he were twenty-three years old at graduation, which, in the writer's opinion, is the most desirable age for starting life as an engineer, he would now be from thirty-two to thirty-five years of age.

If he feel that he is old enough and has had sufficient practical experience, he can now start in for himself by hanging out a shingle in the city of his choice. But if, on the contrary, he feel at all diffident about starting thus, or if he have been unable to save up to this time a sum of money amounting to at least one thousand dollars, it will be better for him to take a year or two more as a subordinate in the direct line of his future work, with either some bridge engineer or some bridge building company, obtaining now as remunerative a position as he can; for with his ten or twelve years of experience his services must have become of real value to those who employ him. If he have not already done so by this time, let him now obtain a thorough knowledge of the designing of train sheds, going into the study of every detail; for such knowledge will stand him in good stead in the years to come.

When at last our engineer has accumulated enough technical experience and capital and has developed sufficient confidence in himself to warrant him at least in launching his bark upon the seas of practical life, he must not be discouraged if at first he finds that the waters are rough and that the currents and counter currents of competition and envy render the steering difficult. All that is essential is for him to maintain a brave heart, keeping his eyes fixed upon the harbor of his ambition, steering as straight a course as the aforesaid currents will permit, until finally he reach comparatively calm water, by which time he will have learned how to handle his craft, if not with ease, at least without undue anxiety.

The conscientious engineer will at the start, and perhaps for several years, be burdened in mind with the responsibilities of his calling, because the lives of many people will depend upon the thoroughness of his work. For a while he will, naturally, worry over details, especially when his past experience fails him, as it often will, and each trifling error in his work, which the most painstaking cannot avoid making occasionally, will render him doubtful of the correctness of all that he does or has ever done, until presently he finds that, by a system of checks and counter checks on all his calculations and drawings, he can assure himself that no error of any magnitude has crept into his results.

After this his mind becomes relieved to a certain extent; but it will never be entirely free from the responsibility that attends those who design and carry out great engineering enterprises.

As soon as business begins to come into his office, our engineer will find that it is absolutely necessary to manage his affairs systematically, keeping all records so that he can always find what he wants, without a minute's loss of time, and making a copy of some kind of everything that goes out of the office. Further, too, than this he must carry his system, by compiling directions as to how to do future work, based upon the past experience of the office.

Then the problem of what employees to engage and to keep will be a difficult one to solve, for an engineer's work comes in by fits and starts, rendering it necessary at times for the entire office force to toil day and night, week days and Sundays, until the work on hand be completed, after which there may be a slack time of longer or shorter duration. The art of keeping his force employed advantageously during such slack times is one that our engineer will have to acquire. Of course, it is practicable to hire from time to time extra draftsmen to aid when there is a rush of work, but such draftsmen as can be picked up hurriedly are seldom capable of making a respectable tracing, much less of doing any designing; consequently, it is upon his trained office force that our engineer will have to rely in emergencies. It is evident, therefore, that the more friendly the footing between employer and employees, the better in every way for all parties concerned.

Respecting charges for engineering work it will be necessary to give our engineer a hint by saying that, if a man fail to appreciate his own merit and worth, it is not likely that others will appreciate them either, and that within the limits of reason the more an engineer charges for his professional services, the more highly thought of he will be by the parties who employ him.

It is true that he will oftentimes lose work by the largeness of his demands, but sometimes the very parties who have refused to accept his terms will come back to him with a request that he take up the same work which they had entrusted to cheaper engineers, and which was botched, if not entirely ruined, in consequence. Such lessons as these have a very salutary effect upon the public and aid an engineer in establishing his reputation.

And now that we have brought our engineer into a successful business practice, we shall leave him there, feeling confident that his painstaking thoroughness, conscientiousness, and integrity will be sure in the end to enable him to reach the most lofty heights of professional ambition.

COMMENT.

In good times, when the services of the engineer, experienced and inexperienced as well, are in great demand, the young engineer may choose his work to suit a definite plan, but in dull years his choice is somewhat limited, and he may find it essential to take up a line of work which does not fit into his scheme. In this event the loss is not usually great, for even undesirable experience serves to strengthen and broaden the mind and develop judgment. A well considered plan which will lead to a high professional position is of great service, but more or less deviation from it should not be a serious discouragement, since any work well done will afford much preparation for practice in the chosen specialty. This fact, however, should not lead to the easy abandonment of any part of the predetermined plan, because perseverance and enterprise will ordinarily make it possible to obtain the work desired if the compensation be subordinated.

Consequently, the plan Dr. Waddell has outlined is thoroughly sound and may be followed advantageously by the engineer who aims to become a bridge specialist. If his ambition is not set so high, and it is self-evident that comparatively few can satisfy such an ambition, the severity of the preparation will be relaxed and more than a nominal salary will be sought long before the tenth or twelfth year after graduation. In fact, the love of money, the desire to marry and to earn enough to support a family, or the desire to hasten the success which is measured by money, leads the majority to abandon such high ideals early in the race.

But there are many important positions for which the training discussed is eminently suitable. The chief and principal assistant engineers of the bridge companies; the engineer of bridges of a railway company, a position which often leads to that of chief engineer; and the bridge engineer of a large city are of this character. In fact, there is a large and desirable field for men well and broadly trained for bridge engineering.

There is no doubt that a sound technical education is a prime requisite nowadays. There are many successful engineers who lack the college training, but they are generally among the older men. The lack of the school training will soon show itself very plainly in a young engineer, no matter how much experience he has had or how hard he has worked to overcome the deficiency. The lack of thoroughness and breadth of training will appear unexpectedly and generally to his detriment. In most manufacturing plants where engineers are employed, graduation from an engineering school of established reputation is almost an essential qualification.

As the engineer increases in years and as his services grow more valuable, the tendency to change his position decreases rapidly. Experience in one line of work renders his services valuable in that line and diminishes the probablity that he will broaden his knowledge at the expense of his salary. Consequently, radical changes of work should be sought in his earlier years if he is to be broad.

The period during which very subordinate positions must be occupied in order to gain experience in many lines should be made as short as is consistent with a sound training in those lines, for long continued work as a subordinate is apt to deprive even a strong minded man of much of his self-confidence and cause him to depend to an injurious extent upon his superiors for direction. The work of large corporations is wisely reduced to a system which is made as nearly automatic as possible, and in these establishments the man who has no executive duties, who is responsible for no work but his own, soon loses his individuality.

It requires courage and energy for a man who has reached a position of responsibility in one line of work to take a similar position in another line with which he is but slightly acquainted, but these are two of the leading characteristics of a successful engineer, hence, if the new position offer the right kind of experience, he should not hesitate. The experience to be gained in a position of only moderate responsibility is very much greater than that obtainable from a very subordinate position, hence responsibility should be sought as early as possible.

In following the plan of staying in one position only so long as it is possible to learn rapidly, there is danger of a serious mistake. The writer recalls a bright, but conceited young man, who had spent but three weeks in the drafting room of a bridge company when he demanded work in the designing and estimating department, saying that he had acquired a thorough knowledge of detailing. Then he spent some months contentedly calculating weights for estimating purposes. Too often a young man thinks he has mastered a subject when he has gained only a very superficial idea of it. But sure, sound designing must be based on a thorough knowledge of details.

The range of work which an engineer who aims to attain eminence in bridge design should understand is exceedingly wide, for the engineering pertaining to the development of a large improvement cannot be so divided that each line may be given to a specialist, consequently, it will be obtained by some one who is capable of planning the whole. The financial problems, the operation of the property, depreciation and the methods of maintenance, increase in value, and all such matters must be thoroughly understood if the engineering is to be of the highest character.

One of the most serious objections to continuance in subordinate positions is the inability to obtain a knowledge of money values of engineering construction. Manufacturers jealously guard their prices and costs, but even where these are known the basis of their make-up is still unavailable. and without it actual figures are of small value. Even the itemized prices bid upon various kinds of materials and work of which a piece of construction consists, afford small clue to true values, for bids are generally balanced for diplomatic purposes. If it be found possible to obtain a few months' work in the cost accounting office of a manufacturer or contractor, the opportunity should be promptly seized.

There is a vast difference between casual examination of a piece of work to learn how it is done and direct responsibility for it, consequently, no amount of such inspection will serve instead of detailed experience. Inspection of the right kind, in which responsibility for the fulfillment of the specifications is an essential part, is excellent experience, but even it will not bring out the reason for the design. It will, however, be exceedingly valuable in showing what is difficult and expensive to construct. Cases in which the purchaser pays dearly for the designer's lack of knowledge of construction are by no means infrequent.

Unless advised by an older engineer, the recent graduate will hardly be able to map out for himself a course of preparation such as Dr. Waddell has indicated; and even when such a course is laid out, it will be found substantially impossible to follow it strictly, because opportunities do not offer themselves in the order desired, and frequently unexpected opportunities occur to gain excellent experience which is not down on the schedule, and it is not always wise to stick to the plan and let them pass. And sometimes in dull seasons there is little or no choice of employment. But it is not difficult to adhere to a general plan close enough to satisfy the purpose for which it is made.

All this variety of experience is sought for the sake of information in the branches of engineering which are intimately related to the chosen work, hence all data which are considered valuable at the time they are collected should be systematically recorded. The plan of carrying in the pocket a bunch of loose cards of suitable size and recording data as it is obtained is excellent, as it enables the matter to be classified and filed at once without rewriting. When properly indexed these cards form a useful permanent record. From time to time they should be gone over, data of doubtful value eliminated, erroneous information corrected, and scattered ideas collected and condensed.

This mass of data will ultimately form the engineer's own pocket book and be infinitely more valuable than the published works of the same kind, for he knows its origin and reliability. It should contain full reference to the books he has read and serve as a working index to his library.

In all his experience the young engineer will find that truth, honesty, judicious frankness, and a cordial, helpful attitude toward his fellows are the most satisfactory means he can employ to gain his ends. They cause no regrets, they make friends, and they gain assistance and advancement. Sharp practices bring but temporary advantages, if any at all, for an engineer's reputation follows him persistently.

One of the consulting engineer's chief assets is his acquaintance, consequently, no effort should be spared to meet men in all lines of business.

Membership in the national engineering societies is valuable because it compels contact with other engineers and invites free expression of ideas. It is, in the public estimation, a guarantee of a certain professional standing as well. Consequently, the young man should join the best societies in his line of work, and take an active part in their proceedings. Competition grows more severe as the grade of work done grows more remunerative and more desirable. A high reputation is probably much more difficult to obtain than money, but it is a prize well worth winning. Money is not to be scorned, but it is not the chief object of desire in the life of the true engineer. The greatest satisfaction in life springs from good and noteworthy work honestly done, a high professional position, and the cordial esteem of one's fellow men.

FOUNDATIONS
FOR
IMPORTANT BUILDINGS
IN THE
CITY OF MEXICO.

By J. A. L. WADDELL,
CIVIL ENGINEER.

INTRODUCTORY NOTES.

Dr. Waddell has done considerable professional work in Mexico within the last five years and has spent altogether probably a year in the City of Mexico. A protracted visit made in the winter of 1899-1900 gave him an excellent opportunity to make a study of foundations for the heavy buildings of the city. It is well known that the city rests or floats on the bed of an ancient lake and that the load is carried on the thin surface strata which confine the semi-fluid material beneath. Variations in the character of the soil and the loads placed upon it cause unequal settlement, consequently, heavy buildings crack and get out of plumb.

The construction of an important public building was under consideration during the winter of 1899-1900 and has since been begun. Dr. Waddell worked out a plan for the foundations, and, for the purpose of having it adopted, had several interviews with the architect for the building, who favored it at first and then, in true Spanish fashion, suddenly refused to consider it further. The paper which follows was then prepared and published in Spanish by the leading daily paper, and in English by the Mexican Herald in March, 1900.

The soft soils commonly encountered in this country are very uniform in character, consequently, the method of constructing the foundations so that each square foot of earth will bear the same amount of load insures uniform settlement and a thoroughly satisfactory foundation. But the materials which underlie the City of Mexico are not only very soft but exceedingly variable in character, consequently, the plan which is so successful in this country, would ordinarily result in failure there. Dr. Waddell's plan consists of constructing the ground floor so rigidly that the unequal load of the building it supports and the unequal supporting power of the material below will not distort it. If the frame of the building be of steel, this rigidity can be most economically obtained by means of vertical bracing lying in the walls and partitions, using the girders to distribute the load locally only, but if the superstructure be entirely of stone or brick, the girders must be heavy enough in themselves to maintain the plane of the ground floor, regardless of the inequalities of the load and the supporting soil. This construction will cause the building to act as a unit and thus prevent cracks and unequal settlement. It is, of course, possible for a building thus constructed to settle more on one side than on another and thus get out of plumb, but this is exceedingly improbable if the load be at all proportionate to the supporting power of the soil.

There is now under construction in the City of Mexico a five-story office building whose plan dimensions are 100 by 150 feet. In constructing the foundations, loose earth was excavated to the depth of five feet and replaced by concrete. A network of loose I-beams spaced about one foot apart and firmly bolted together was laid upon this concrete base. The spaces between the beams was then filled with concrete, and steel girders which carry the columns are placed above the floor thus formed.

This concrete base, which is six feet thick, weighs almost 1,000 pounds per square foot. Since the soil will not carry more than 1,200 pounds per square foot with safety, it is quite apparent that the earth beneath this building will be overloaded.

A proposed hotel building for Mexico City, for which Dr. Waddell prepared the foundation plans, is eight stories high, yet would have exerted a pressure of less than 1,200 pounds per square foot on the soil if the structure had been built according to Dr. Waddell's figures. The weight of the foundations would have been only about 150 pounds, while the construction of the walls and floors was made as light as possible, and the live load assumed to act simultaneously on all eight floors was the smallest which may be legitimately used for a hotel building.

The only satisfactory features of the design for the foundations of the office building above mentioned is the continuity of the concrete; but this could have been obtained at less expense by substituting reinforced concrete girders for the steel girders proposed in Dr. Waddell's design and employing a pavement of six or eight inches of reinforced concrete instead of his pavement construction. This suggested construction would have weighed more but cost less than the construction proposed by Dr. Waddell; and it would probably have cost less and certainly would have weighed much less than the foundation which has been constructed.

FOUNDATIONS FOR IMPORTANT BUILDINGS IN THE CITY OF MEXICO, WITH SPECIAL REFERENCE TO THE NEW LEGISLATIVE PALACE.

By J. A. L. Waddell, C. E., B. A. Sc., Ma. E.

Written for the Mexican Sunday Herald.

During the past twelve months the writer has had occasion to study the peculiar conditions of the soil in the City of Mexico in relation to the erection thereon of large and important buildings, with the result that he has evolved a new type of foundation which, in his opinion, is the only one that will render heavy constructions here safe against not only injury from unequal settlement, but also damage by earthquakes.

Concerning earthquake phenomena and their effects, the writer feels that he can speak with some authority, having spent four years of his professional career in Tokyo, Japan, where there are recorded on the average over one hundred earthquakes per annum.

As there are in both contemplation and actual construction in this city several buildings of great size, the time is opportune for a discussion of this important subject of foundations; so the writer has prepared this paper and has had it translated into Spanish in order that it may be published simultaneously in two of the leading dailies of the city, his intention being to start a discussion that may lead to the inauguration of some badly needed improvements in local building construction.

No observing man can traverse the City of Mexico without being impressed most unfavorably by the many cracked masonry walls, the lack of verticality of tall buildings, the ugly sags in façades and the painfully prominent inclinations to the horizontal of masonry courses that were certainly intended to be true.

Some of the cracks were probably caused by earthquake shocks, but most of them, as well as the other objectionable features just mentioned, are due to the low supporting power of the soil and to the neglect of the architects to meet properly the conditions induced thereby.

As glaring examples of the dire effects of failure to design foundations properly for the soft soil of the city, the writer would name the following:

The School of Mines.—This building is badly sagged in the centers of all three frontages, and is decidedly out of plumb. It is also cracked and has sunk materially.

THE SCHOOL OF COMMERCE.—This building, which adjoins the School of Mines, is extremely distorted, besides being badly sagged, especially on Calle Sta. Isabel.

THE PROFESA CHURCH.—The tower of this handsome structure is so out of plumb as to remind one forcibly of the Leaning Tower of Pisa.

THE SANTA TERESA CHURCH.—The variations from verticality in this building are extreme; and it looks as if some settlement had occurred during construction, because there are walls slightly battered below and vertical above. If this feature of construction existed in the original design, it was, to say the least, very peculiar.

THE NORMAL SCHOOL.—The top of this building, which is adjacent to the Santa Teresa Church, has receded quite perceptibly.

THE NATIONAL PREPARATORY SCHOOL.—(Formerly named San Ildefonso College.)—This large structure has pitched so much to the east that there is a difference of level at the two sides amounting to about six feet. Moreover the façade has warped in a most unsightly manner.

THE NATIONAL PALACE.—This immense building shows many cracks, and is undergoing numerous repairs, necessitated by settling foundations.

THE CATHEDRAL.—Even this fine structure is not free from cracks; and it is a well known fact that a great deal of repair work has been done on it in times past.

CALLE PATONI NO. 6.—This is a handsome new residence that has sunk fully a foot, and has dragged down with it the two adjacent buildings. The sidewalk now pitches considerably towards the building instead of away from it, as it must have done at first, and the rain water now drains into the patio instead of into the street.

THE EPISCOPAL CHURCH.—This structure located on Calle Providencia, was built only five years ago, and is already settling so as to crack the paved floors. The tall stone columns of the gateway are being tipped towards the building; and, as these were built only a year and a half ago, the tipping shows that the sinking of the building is gradual and continuous.

GROUP OF THREE-STORY BUILDINGS ON THE CORNER OF BUCARELI AND PROVIDENCIA STREETS.—These heavy masonry buildings have caused a settlement of as much probably as two feet over a large area at the corner, and it is said that during heavy rains the water stands a foot and a half deep in the patio. The buildings are cracking to pieces and are decidedly out of plumb.

THE NATIONAL RAILWAY COMPANY'S DEPOT.—This is an expensive and handsome structure substantially built and well finished; nevertheless, as far as foundations are concerned, it is an excellent illustration of "how not to do it." The said foundations are fourteen feet deep and the walls at the base are nine feet thick, involving the use of such a mass of material as to overload the earth without any assistance from the superstructure. The reason for making these foundations so deep was to reach the so-called tepetate stratum.

The entire building has sunk considerably, as the depressions in the fence walls and the ground show. This depot is not yet five years old.

UNFINISHED BUILDING AT THE CORNER OF THE PASEO AND CALLE PENITENCIARIA.—This has evidently sagged during the construction of the walls, for the lower courses show much more deflection than do the upper ones, the cornice at the top appearing to be truly horizontal.

THE EX-ARCHBISHOPRIC.—This structure was erected in A. D. 1745. Its interior arches are cracked, and both external faces are considerably warped.

Bad as is the soil of the City of Mexico (and it would be difficult to find anything much worse for foundations), there is no reason whatsoever for failure of any kind in buildings that are properly designed to meet the conditions of the soil and those due to earthquakes. This may seem to be a rather sweeping statement, but the writer does not hesitate to make it, and to back it with his professional reputation.

In order, however, to obtain immunity from the aforesaid dangerous conditions, it will be necessary for Mexican architects to modify many of their old methods of building construction, and to not only adopt the latest ideas but also go a step farther and accept some new ones, evolved especially to meet the peculiar conditions existing in this city.

As is well known, the City of Mexico is located on the bed of an ancient lake; and by digging down but little more than a metre, water level is reached. The characteristics of the soil vary somewhat in different parts of the city; but, in general, it may be stated that there are some two metres of a soft, sandy clay overlying a stratum of so-called tepetate, which is really little else than a more solid layer of the superimposed earth, and not true tepetate at all. This stratum is on the average less than a metre in thickness, and below it lies an extremely soft mud of indefinite depth.

Such being the case, the following axiomatic conclusions may be drawn:

1st. Piling is not applicable for consolidating the ground; because there is no firm bottom for the piles to reach, and because the soil beneath the hard stratum is of too fluid a nature to offer any material resistance by side friction.

2d. The hard layer should under no conditions be disturbed, and the total load that it sustains should be distributed over it as uniformly as possible.

3rd. The more of the existing soil that is left undisturbed over the hard layer, the more uniform will be the distribution of the load over the latter.

4th. The less material used in the foundations of a building, the smaller will be the weight of the said foundations, and the greater will be the permissible load from superstructure that can be adopted.

The general opinion in Mexico appears to be that a total superimposed load of one thousand (1,000) lbs. per square foot is about as high as can be considered safe for the soil of the city; but, if the writer had any important building to design, he would certainly first make a number of tests of the actual bearing capacity of the soil, and would be governed by the results thereof in proportioning the entire structure.

As in any area of any magnitude, the soil overlying the hard stratum is much softer in some places than in others, it is impracticable to adopt the customary American method of so distributing concentrated, isolated loads as to insure a uniform settlement of the entire building; consequently, if this method be tried, it will certainly result in failure.

Again, the haphazard method of placing beneath the walls masses of concrete containing steel rails will not suffice; because such masses will not have the necessary strength and rigidity to prevent unequal settlement and the consequent cracking of the walls.

With very soft soils of uncertain and unequal bearing power, there is but one method of preparing a foundation for a large, heavy building, that will ensure the structure against failure by cracking, and that is to support the superstructure upon a continuous platform of steel encased in enough concrete to preserve it effectively against oxidation, the said platform having sufficient strength and rigidity to bear without appreciable distortion all inequalities of loading from above, due to variations in amount and position of the live or moving loads, and to take care of the prejudicial effects of the unequal bearing capacity of the soil at different parts of the foundation. Or, in other words, the building should be floated on the soft soil by making it into a box with a rigid, continuous bottom.

If the building be an isolated one in reference to other buildings, the platform can be extended beyond the walls so as to provide a much greater bearing area, and thus permit the adoption of an increased number of stories; but, if the said building be one of a block of houses, the base can be cantilevered out only into the street or alley (if there be one); consequently the number of stories will then be limited by the allowable maximum pressure on the soil.

This is the type of foundation evolved by the writer specially for large and heavy buildings in the City of Mexico. It will certainly (if properly detailed) prevent all injury to the buildings from unequal loading and unequal supporting capacity of soil, and will aid materially, if not perfectly, masonry walls to resist earthquake shocks. However, to ensure the walls against damage by the latter, the framework of the building should be of steel construction; but of this, more anon.

The details of the writer's proposed type of foundation are as follows:

1st. If the surface of the ground be very soft or irregular excavate to an average depth of a couple of feet the entire area to be occupied by the platform, then roll with heavy rollers the bottom of the pit thus formed until the bed is firm, filling in with a mixture of clay and gravel any inequalities caused by the rollers traversing earth of varying softness, and keeping the rolled material slightly damp by sprinkling it with water from a cart.

Next put in a thin layer of clay and gravel, dampen it, and roll it until it is compacted thoroughly, then another similar layer and another until the surface of the base is brought up to or a little above the average original level of the ground.

2d. Lay out the steel work of the base so that the main girders come under the lines of the walls and columns, making them all of the same depth so that, by placing splice plates above and below at the intersections, all girders will be continuous from end to end.

The proportioning and detailing of these girders constitute an engineering problem of no mean order, as it is these girders alone that must take care of all inequalities of both loading and bearing resistance, unless steel superstructure be adopted, in which case sway diagonals embedded in the walls will aid materially in resisting the bending caused by these inequalities, and will thus permit of a reduction in the amount of metal required in the base.

3rd. Next, run primary girders at convenient distances apart, parallel to one set of the main girders and riveting into the other set. These girders will carry no load except the local upward pressure from the soil pertaining to the small areas that they dominate.

In section these primary girders can be either large rolled I-beams or small built girders.

Next, run small secondary girders into and at right angles to the primary girders, thus dividing the total area into small rectangles that are approximately squares. These secondary girders should be small rolled I-beams.

Finally, run tertiary girders of still smaller I-beams into and at right angles to the secondary girders.

The upper surfaces of the main, primary, secondary and tertiary girders should be approximately at the same level.

It is almost unnecessary to state that, between the ends of the main girders which are cantilevered beyond the exterior walls, there are to be primary, secondary and tertiary girders like those in the space bounded by the said exterior walls.

4th. If there are to be steel columns in the superstructure, these should be located directly above the intersections of the main girders of the base, and should be so designed as to rivet into the latter and be braced thereto substantially by steel brackets or knees, which will lie within the walls.

5th. The main and primary girders are to be sunk into the earth by excavating trenches therein, but the secondary and tertiary girders are to lie above the surface of the ground.

There is to be a single layer of concrete covering the whole area and enclosing all the secondary and tertiary girders; and the portions of the primary and main girders which project below this are to be encased in the concrete with which the trenches in the earth are filled.

By this design the weight of concrete in the base is reduced to a minimum, thus leaving the greatest possible portion of the permissible earth load for sustaining the weight of the superstructure and its live load.

6th. This design reduces the functions of the concrete to merely two, viz., to act as a protecting covering for the steel, and to carry the upward pressure of the earth to the secondary and tertiary girders.

7th. The detailing of the metal-work in the base, the location of girders and the splices in same, and the *modus operandi* of erecting the metal and placing it in the concrete are engineering details of a purely technical character, so it would be out of place to treat of them in a general paper like this, written, as it is, as much for the public as for the architects and engineers of the City of Mexico.

And now a few words as to the suitability of skeleton steel construction for buildings in the City of Mexico. In the writer's opinion, it is, for the following reasons in every way eminently adapted to meet the unusual conditions of soil and earthquakes:

1st. Such construction is ever so much lighter than that of masonry, thus reducing the load on the foundations and permitting the adoption of fully twice as many stories as are now generally used for buildings in this city.

2d. It permits the use of sway bracing in the walls, which insures great rigidity against unequal settlement and earthquake shocks.

3rd. It permits of much better lighting than does any other kind of construction, for all exterior walls may be composed almost, if not quite, entirely of steel and glass.

4th. It adapts itself readily to any style of architecture and to any kind of exterior finish.

5th. It accommodates itself to any desired interior layout, and permits of greater room space because of the thinness of the walls.

6th. Under ordinary conditions of the material market, it is much cheaper than masonry construction or any other construction approaching it in efficiency and durability.

7th. It can be made more nearly fireproof than can any other type of construction.

8th. The time required for completing a steel building is only one-half of that usually necessary for erecting a corresponding structure in masonry.

In order to meet properly the peculiar conditions of soil and earthquake shocks, steel buildings for this city should, in the writer's opinion, be decidedly superior to those of the United States, where the conditions are far less trying.

The following are the principal improvements which the writer would suggest, in addition, of course, to the continuous steel and concrete platform:

1st. That diagonal sway bracing, in planes parallel to both of the rectangular co-ordinate vertical planes, be employed wherever the architectural features of the building will permit.

2d. That in all wall panels, where such diagonals must be omitted, there be placed in each of the four corners of the rectangle a substantial steel bracket attached firmly to both post and girder.

3rd. That rivets instead of bolts be used throughout for all connections.

4th. That the most approved specifications for steel bridges be adopted for the manufacture and erection of the metal-work instead of the much less rigid specifications employed for American steel buildings.

This refers especially to the reaming of all rivet holes and to the planing of all abutting ends, so as to insure perfect fittings.

5th. That all floors be built of concrete manufactured with the light volcanic rock so common in Mexico. This rock, of course, would not answer for the base; because its porosity would permit of water reaching the metal-work.

6th. That the use of wood be avoided wherever it is practicable to do so; entirely, if possible.

In respect to the greatest practicable number of stories for buildings in this city, it is the opinion of the writer that for isolated structures the limit is eight, and for buildings in blocks five or perhaps six, except in case of structures on corners where it is permitted to cantilever the foundations out into both streets, in which case seven stories would be practicable, or perhaps even eight.

The writer has already made for the City of Mexico a design for the foundations and metal-work of an eight-story hotel of steel construction; and hopes to have, in the near future, the superintendence of manufacture and construction of same.

There certainly will be built here ere long one or more large steel office buildings, as there is a great demand at present for office room, and as there exists much dissatisfaction with the character of the present office accommodations.

The new Legislative Palace, which is now being designed, is intended to be a monument of construction for future centuries; nevertheless, it was evidently at first the intention to adhere more or less to the old type of foundations, which has proved so unreliable in the past.

The writer has had during the last three months several consultations with the architect of the building, and has made him two important suggestions, viz.: That he adopt the floating steel and concrete foundation herein advocated, and

Second: That he have made a complete design and estimate of cost of an all steel and concrete superstructure with only the exterior walls of stone, the latter being made very thin, so as to keep down the weight of structure as much as possible.

Neither of these suggestions was accepted.

Now as the writer certainly originated the floating steel and concrete platform, and as, in his opinion, it is the only kind of foundation that will ensure any large building in this city against injury by unequal settlement, and therefore is likely to be adopted, he desires to call the attention of the people of this city to that fact; so that, if his type of foundation be used, he will receive credit for the design.

That there is need for the utmost precaution in designing foundations for the Legislative Palace anyone can see who will inspect the site, where the area to be occupied has been excavated thus far to the depth of one metre. Not only is the material of the softest and most unreliable character, but it also varies much in softness at different parts of the excavation. Again, the test pits that have been dug show that the earth is worse below, and that the so-called layer of tepetate is not only thin but also of a most unsatisfactory character in respect to sustaining power.

If the writer were the architect of such an important building, he would most assuredly exhaust all the possibilities by studying thoroughly all approved types of construction, especially the most modern ones, and would prepare a complete design and estimate of cost of an all steel and concrete structure with thin masonry facing stones, resting on the firmest and most substantial foundation possible. The expense involved in such a study is a mere nothing compared to the total cost of the building, and should not be considered for an instant in view of the importance of the proposed structure and the necessity for making it absolutely safe for all time, beyond the peradventure of a doubt, against all possible contingencies.

In making comparative estimates of cost of steel and other buildings, it must not be forgotten that the present price of structural steel is more than twice as great as it was less than two years ago, and that, in all probability, it will ere long drop back to its normal amount; for steel manufacturers cannot continue to sell for an indefinite time their product at a profit exceeding one hundred per cent. The latest quotations on metal-work made to the writer indicate a falling tendency.

In concluding this paper, the writer can do no better than to quote an apparently paradoxical axiom that he has established for building in Mexico City, viz., that "the heavier and more substantial the walls, the weaker the structures to resist the injurious effects of settlement and earthquake shock."

City of Mexico, March 12th, 1900.

ADDRESS

BY

J. A. L. WADDELL

TO

THE GRADUATING CLASS

OF

THE ROSE POLYTECHNIC INSTITUTE.

JUNE 12, 1902..

INTRODUCTORY NOTES.

The address to the Graduating Class of the Rose Polytechnic Institute was delivered in 1902, consequently it contains Dr. Waddell's present ideas of the course a young technical graduate should pursue in order to become a successful engineer. Twenty-seven years of experience, six in teaching and twenty-one in practice, had taught him the deficiencies and weaknesses which ordinarily retard the young engineer's progress, and his ever ready interest in his fellows led him to point them out in order that they might be remedied.

Throughout his professional career Dr. Waddell has constantly endeavored to help other engineers, especially young men just from college, not by advice alone, but in many direct and substantial ways. It is not probable, however, that any other form of assistance is so beneficial as sound, comprehensive advice, so given that it is impressed firmly upon the mind of the young man. Very commonly the engineering graduate has spent all his youth in school and possesses no first-hand knowledge of the world of business. He enters upon his new duties eagerly and searches restlessly for information upon the practical phases of his work, business methods, business and professional ethics, and the relations between the engineer and the contractor. He is very impressionable and easily influenced, consequently, to lead his thought into right channels at the outset is an incalculable service. It is especially desirable to point out the necessity for hard work, strict attention to detail, and continued study; for too commonly the recent graduate thinks he lacks only the practical knowledge of his subject.

The procedure advised will undoubtedly keep a young man busy and is sound in the main. Serious exception may be taken, however, to the strictures against municipal service. The work for which cities employ engineers is of the highest importance and requires something of the skill and tact of the politician, as well as engineering knowledge. It is true that "practical politics" is commonly odious to the scientific man who is intent upon rendering the best possible service, but it is rare indeed that the engineer is free to act according to his best judgment, no matter what his position. If he be in the employ of a manufacturer or a contractor, competition forces him to adopt many methods which fall short of the best. Even the consulting engineer is often vexed by restrictions which his clients force upon him. In no case is one absolutely free to act according to his judgment except, possibly, in some private matters.

But there is great public work to be done, and honest, capable men must be employed to do it. The civil engineer who enters the employ of a public corporation will encounter many annoying obstacles. Politicians will endeavor to force incompetent assistants upon him; with good intent and bad, his work will be unfairly criticised; due honor and credit will be denied him; he may even be persecuted for taking his stand against corruption; but in spite of these unpleasant features of his position, he is in duty bound to conduct his office for the benefit of his employer, the public. The more difficult the position, the more credit is due if it be honorably filled. The harder the battle, the stronger the victor will be.

The matter of credit for work done will always be a vexatious subject. Many older engineers are thoughtless and cause much hard feeling by neglecting to give due credit to their assistants; occasionally there is a man who is unwilling to be fair in the matter and who selfishly takes to himself credit which does not properly belong to him; but as a general rule, credit is freely given where it is due. The young man, however, is apt to exaggerate the importance of his part and to feel unduly aggrieved to find little attention given to his share in the work. He underestimates the importance of the broad planning which his superiors have done and considers the detailing which generally falls to his lot to be more important than it is. Engineers in authority should be careful to commend the good work of their assistants publicly, if the matter be discussed in the technical press, for even increased compensation is less gratifying as a measure of success than open recognition of ability.

In his comprehensive review of the civil engineering field, Dr. Waddell has rendered the graduates whom he addressed no small service, for they generally have very vague ideas of what constitutes the work of the civil engineer. In choosing his course the young man generally errs because he does not have a clear conception of the various steps which lead to a high professional position, rather than through the lack of sound principles, and he welcomes the views of the older and successful engineer; consequently, such addresses as these are never written in vain.

TO THE MEMBERS OF THE GRADUATING CLASS IN THE ENGINEERING DEPARTMENT OF THE ROSE POLYTECHNIC INSTITUTE.

GENTLEMEN:—When your worthy President did me the honor of inviting me to address you on this auspicious occasion, I was sorely tempted to decline, because of the vast amount of professional work with which my associates and I are at present struggling. This is by far the busiest period of my entire career, and possibly you know that my life has not been an idle one. Notwithstanding this state of affairs, I concluded to accept your President's invitation, because I recognize that it is an important part of an old engineer's duty to aid young engineers in making their start in life.

I feel that I must begin with an apology for reading to you a typewritten address, assuring you that, as an extempore speaker, I am an utter failure, unless it be when lecturing on technical subjects; and I think that you will agree with me that a fair written address is preferable to a poor extempore one.

Your President has left to me the choice of a subject, merely suggesting that I give the boys some good advice and try to make my remarks of general interest so as to reach others than the engineering graduates. With the first portion of his suggestion I most readily comply; but I must beg to be excused from the second, as I am no hand at making popular speeches. My remarks then, young gentlemen, will be directed to you solely, hence those of my hearers who do not belong to the graduating class are destined, probably, to have a stupid time, but I can promise them that it will be comparatively short.

An engineer's success in life depends greatly upon two things: First, the thoroughness with which he has pursued his studies at his technical school; and, second, the start that he makes immediately after leaving there.

In respect to the first matter, I assume that the conditions here, like those that have always existed at that other and older R. P. I., of which, by the way, I have the honor to be an alumnus, are such that no student who has failed to attend strictly to business during his four years' course is able to be present to-day in the graduating class, and that consequently you all are in good shape as far as the first requisite is concerned. It is of the second, therefore, that I shall now proceed to treat, by giving you some wholesome advice, based not only upon my own professional experience, but also upon that of other engineers of my acquaintance, and having due regard to both successful and unsuccessful careers.

Generally speaking, advice to young men is a wasted effort, for it goes into one ear and comes out of the other (concerning this I can speak authoritatively, for I am trying to rear two boys of my own); but in your case I hope for better things than ordinarily, as this is a momentous period in the life of each of you. Let me assure you, young gentlemen, that there is nothing which will be so conducive to your professional success as good advice from older engineers, whether they be successful men or not. In the case of the former, they can tell you what they did in order to reach the desired goal; and in the case of the latter, you can learn what they failed to do and what mistakes they made. So let me begin my suggestions by counseling each of you to become intimately acquainted with one or more successful engineers, and, craving their advice and opinion from time to time, follow both.

Young men just leaving their *alma mater* naturally feel that the whole world is before them, and that their success is almost an assured fact; but I tell you that you are very liable to find it otherwise, that you will undoubtedly experience many hard knocks, that at times you will feel very dubious as to what is best to do, and that you will often long for counsel from some friendly member of the profession whose opinion you can trust.

It is on this account that I advise you to become acquainted with your brother engineers as far as lies in your power and to impress upon each of them favorably your individuality, that later on you may not be forgotten. Time spent in visiting older members of the profession is by no means wasted, so take it whenever you can do so without neglecting your duties; and endeavor to confine your conversation with such men mainly to technical subjects, preferably those in which they are specially interested. A young engineer can often aid an older one materially by assisting him in some of his calculations and in the preparation of papers for technical societies. What would often be drudgery to the older engineer would prove to be valuable experience to the younger, so never hesitate to undertake, in such a case, tedious computations which will lead eventually to valuable deductions, even though your reward be apparently *nil*. An engineer of the right kind (and I am happy to be able to assure you that most of them can be so classed) is only too glad to give full credit to a younger man who has helped him in his investigations.

Concerning the benefit to be derived from an older engineer's opinion and the need for it, I can speak from experience; for many a time have I received kindly help and encouragement from my good friend, Professor Burr; yet in the old days when we were associated together at Rensselaer, being of nearly the same age, we often got beyond our depth and would have given much for some sound advice from engineers of high standing;

but unfortunately it was not at our command. I can look back upon many a wasted hour in my early days, when, active, energetic, and ambitious, I desired most earnestly to devote my attention to investigations the results of which would prove useful to our profession and would tend to establish my reputation as an engineer and a technical writer. But alas! there was no one to direct my energies into a proper channel or to show me how to employ my time.

Enforced idleness for an engineer is the greatest curse in existence; and there ought to be no excuse for a member of our profession having a single, necessarily idle, hour; because he should always have laid out for the future more things professional to investigate and accomplish than he can possibly perform. It is a serious thing for an energetic young fellow (and all engineers of any account, both young and old, are energetic) to run short of work for any length of time. I well remember a period of eight months of enforced idleness that I experienced a few years after graduating, during which time I nearly wore myself out with worry and restlessness, not having had sufficient practical experience to enable me to write more than a paper or two. It is true that I had saved up quite a little money, enough to tide me over the bad times without having to appeal to my father for assistance, and that during that period I obtained a pretty sound knowledge of the French language; nevertheless, I succeeded in worrying myself absolutely ill. I assure you that I would not go through those eight months again for untold wealth. They are the only part of my life that I look back upon as truly unhappy.

You young men are, in a way, much more fortunate than I was, in that I started my professional career during the depressed years of '75, '76, and '77, while you are entering upon yours at the most prosperous time ever known in the history of America. Never before were engineers in such demand, never before was the compensation for professional services so good, never before was the country so wealthy, and never before were the prospects for the future so bright. Our great republic (and believe me, although alien born, I can truly appreciate its greatness) has entered the world's arena with the intention of taking quickly the first place among nations; and in the peaceful strife that is to ensue, American engineers of all lines will be found in the van, bearing the brunt of the struggle and, even in the most remote corners of the earth, forcing foreign nations to adopt our methods and to purchase the manufactured products of our country.

Ours is truly the greatest of all the professions! With it none other can compare! It, and it alone, is essentially the profession of progress! To whom is due the unparalleled world-advancement of the last half century? Who are the men who have developed the resources of the North American continent? To whom are we indebted for all the great luxuries of modern life? To these questions there can be but one answer:—the civil engineers, using the term in its true and broad sense, so as to include all engineers except the military.

Compared with all other professions, ours is by far the most desirable. Lawyers, of necessity, lose one-half of their cases; so about fifty per cent. of their total work is failure; while all engineering work is, or should be, successful. Half of the time lawyers are retained to disguise the truth or so to distort it as to win cases for their clients, while the engineer is essentially *a searcher after truth.*

The doctor too often gropes blindly in the dark, using tentative methods and relying upon nature to help him out of his difficulties; for medicine is anything but an exact science; while engineering comes nearer being such than does any other profession.

The military man's main object in life is to destroy, while the engineer's is to construct.

The minister deals with things based on faith, while the engineer in all his works is governed by the laws of nature, which, as a rule, he understands fairly well, and with which he must comply in order to be successful.

Civil engineering is the youngest of all the learned professions; and until quite lately many people, including even some of its prominent members, maintained that it was not a profession at all, but simply a trade. However, all that is a thing of the past, and engineers are now not only considered to be professional men, but are looked up to by the populace. "Straws show which way the wind blows"; so, to learn the world's opinion of engineering and the civil engineer, we can consult the light literature of the past and present. It is not many years ago that English novelists sneered at the engineer, terming him a "greasy mechanic" and placing him outside the pale of polite society. At that time American novelists either simply ignored the engineer by leaving him out of their *dramatis personæ*, or, when he did come incidentally into the plot, considered him about on a par with a boss carpenter. To-day all this is changed. Many of the prominent modern novels have civil engineers for their heroes; and in all of them the members of the engineering profession are invariably treated with the greatest consideration. In France and in French literature the civil engineer has always been recognized with due esteem, as is witnessed by the works of Jules Verne and other French writers. There is perhaps good reason for this, because the civil engineer in France for the last hundred years has always been a polished, highly educated gentleman, and generally a graduate of a school of world-wide reputation.

In our country any man or boy that can use a surveying instrument or even drag a chain or handle a rod, has the privilege of dubbing himself a civil engineer, thus lowering the profession in the minds of the public, which generally fails to distinguish between a graduate engineer and one who has risen from the ranks. Nevertheless, nowadays in this country in order to attain anything beyond mediocre success in engineering, a young man must be a graduate of a technical school, and the higher the reputation of this school the better are his chances. It is true that we have in the profession many prominent men who never had a technical school training, but they are almost invariably of advanced years.

In England there have been until lately no special schools for engineers, so the young engineer there has had to obtain his education by the crude and faulty system of apprenticeship; consequently there may have been some reason for the low standing of engineers in the opinion of writers and society people; nevertheless, the English engineer of to-day ranks in his own country second to no other professional man. Again, the Institution of Civil Engineers of Great Britain is certainly the greatest and most influential engineering society in the world; and some of America's most eminent engineers are proud to be able to write M. I. C. E. after their names.

Yes—there is in my mind no doubt about it—ours is the most satisfactory profession of them all, notwithstanding its numerous physical hardships, its grave responsibilities, and its exacting demands upon one's time and energies. Never once since graduation, over a quarter of a century ago, would I for an instant have considered any proposition to abandon the profession of my choice, and never once have I regretted that choice—this notwithstanding the fact that my early experience was anything but an easy one, involving as it did small pay, excessively hard work, long hours, continued exposure to rain and snow, occasionally extreme hunger, unappreciated effort, and sometimes imminent peril to life. Many of these things at the time were intensely disagreeable; but now I look back upon them with great satisfaction, feeling that they were indeed blessings in disguise. Hard knocks tend to develop a man and to bring out the best that is in him; hence if in the near future any one of you have occasion to feel that the world is treating him badly or that he is "out of luck," he should not worry about it, but should proceed upon the even tenor of his way, having confidence that all will come right ere long, and that later he will have occasion to feel thankful for all his unpleasant experiences.

The question that naturally interests you most just now is what work you will start with and possibly what compensation you will receive; hence a few suggestions from an old fellow who has been in harness for many years will perhaps be acceptable.

It is far more important that you obtain good experience than that you receive at the outset a large salary. The services of a newly-fledged engineer are as a rule of little or no account. On some work they have a positive value; on other work they are worth zero, and on still other work they have a negative value. The higher the branch of engineering that the recent graduate enters, the less valuable to his employers will be his services. For instance, in any work of surveying the young engineer from the very first day can earn as much as a teamster, axeman, rodman, or general roustabout, and in a few weeks considerably more; in more complicated work, such as waterworks, sewerage, or railroading, for a few months at least, the value of his services will be approximately zero; while in extremely complicated work, such as bridge designing, the drafting that he does at first either has to be done all over again, or requires so much time for correction as to render it practically worthless; and at the same time he occupies the attention of those whose services cost considerable money and who possess large earning capacity. In our office we estimate that it takes three months to bring the value of the recent graduate's services up to zero, and three months more to recoup the office for its loss on his instruction; so it is not until after six months that his work really begins to become remunerative.

Each of you must judge for himself what class of work is best suited to his needs and conditions. Fortunately for you it is practicable to-day to enter any branch of engineering that you may choose, as engineers of all kinds are in great demand, everybody having more work than he can really do in the short time that is almost invariably allowed on the engineering portion of enterprises.

Some of you are perhaps in need of money, possibly to pay debts incurred in obtaining your education. These I would advise to take positions on railroad surveys, where good salaries are paid at the outset, and where up to a certain point promotion is rapid for a man of the right type. Or if field work be not to your taste, comparatively large earnings can be made at once by entering as draftsman the employ of a bridge manufacturing company. Here the promotion is slow, and the professional advancement is still slower, as it is naturally to the company's advantage to keep a man continuously at one kind of work as soon as he becomes proficient in it. Comparatively good positions can be obtained by joining the engineer corps of a large railroad company, and working up step by step; but the progress is slow, and the plums that can be reached at the top of that tree are only two or three in number.

It is not a bad idea to take a subordinate position in some large manufacturing concern, and work up; for there the possibilities of promotion are better, and there is always a chance of making your services so valuable that you will eventually be taken into the company.

Government positions are fair enough in a way; but they are difficult to obtain, and do not offer much of a field to an ambitious man. About the poorest and most unsatisfactory position that one can take is in the employ of a city, not only because the pay is generally small, but mainly because the tenure of office is so uncertain. Believe me, I would prefer a position as boss grader on a dump to that of city engineer, and I would rather work as a navvy with a pick and shovel than accept a subordinate position in the engineering department of a city. Avoid all political positions; they are badly paid, insecure, and in every way unsatisfactory. It degrades a man, in his own estimation at least, to feel that he is at the mercy of every log-rolling, wire-pulling, ward-politician that may for any reason take offense against him. Engineering positions in municipalities ought to be placed above the control of politics; but how to accomplish such a *desideratum* is more than I can suggest.

As far as the attainment of knowledge and ultimate high advancement are concerned, the best positions to take are those in the employ of consulting engineers of established reputation. Ordinarily these are very hard to get; but at present it is otherwise. In England a young man has to pay handsomely for the privilege of entering such an office and working there for several years without any salary whatsoever; but this custom does not exist in America, owing to the fact that such good training is given in our technical schools.

No matter what branch of engineering you choose, aim always to obtain valuable experience rather than large pay; the latter will follow as a matter of course after the former is acquired.

If I were once more a young man just leaving my *alma mater,* and if I were not cramped for means, I would, for at least five or six years, work in subordinate capacities, for a few months at a time in each position, leaving just as soon as I had mastered the principal engineering features of the work, or just as soon as the daily attainment of knowledge failed to satisfy my desire, and taking up another line of work, in order to secure for myself a sound, practical knowledge of a number of branches of engineering. Meanwhile, I would be deciding on my specialty and gradually turning my energies towards the chosen line of work, to the ultimate exclusion of all other lines; and I would not rest content until after I had acquainted myself with every minor detail of my adopted specialty, so that, after settling down to a private practice of my own, I would feel master of the situation on each new piece of work as it comes up, and would never have any reason to fear that my ignorance of any detail would prejudice me in the opinion of my clients. It would take courage and plenty of it to follow such a course as this; but the ends to be attained would be worth the effort. It is a great mistake for a young engineer to choose a specialty before he has had several years of general experience. What a source of dissatisfaction it must be for a middle-aged man to feel that he has chosen the wrong line of work, and that it is too late to make a change?

It is possible that I am wrong in giving you advice based upon the supposition that you all desire intensely to rise high in the profession, and that you will eventually reach the top of the tree. It is true that all cannot be first and that all have not equal ability; or, to quote the sentiments if not the exact words of a poet that is to-day almost forgotten,

> "Order is Nature's law, and this confessed,
> Some are and will be greater than the rest."

Nevertheless, in my opinion, it is better to strive constantly for a high ideal and fail to attain it completely, rather than to jog along contented with small things and mild ambitions. At any rate, the actual results attained by the former method are almost sure to exceed materially those accomplished by the latter.

From personal experience, I can assure you that it is within your power to attain ultimately your heart's desire for professional advancement and distinction, no matter how lofty your ambition may be, provided that you strive for it faithfully and never despair. To be a successful engineer, one should establish in his own mind (and generally keep them strictly there) certain objects to be attained in both the immediate and the distant future, adding to them from time to time as his experience increases, and never resting content until they are accomplished. Earnestness of purpose is a *sine qua non* for success: without it one may as well consider himself at the outset out of the race. Above all things, don't work by the clock and quit the moment time is up; for if you do, you will soon establish for yourself with your employers and associates the reputation of being a mere time-server. I have on several occasions seen a navvy with a pick poised for a blow, drop the tool upon the first blast of the whistle announcing quitting time. Such an action may be excusable in an ignorant workman, but it would not be so in a member of the civil engineering profession.

Some engineers pay their assistants for overtime, while others do not. I have tried both ways, so am able to say which is the better method; and this is my judgment: The overtime system is more satisfactory to the average draftsman, and at the same time is really better for the employer; because he then pays for only the hours actually spent on the work, counting out all lost time, and because he feels no hesitation in asking his men to work nights and even Sundays when occasion demands. Nevertheless, I have noticed that the young engineers who have risen the most rapidly are those who have never been paid for overtime; and this stands to reason, because an employer of the right kind feels that in common decency he must promote rapidly any employee who shows such an interest in the work as to labor overtime without thought of extra compensation.

In all your work cultivate to the utmost the attributes of reliability and accuracy, and never let any computations be used unchecked, the checking being done either by an independent computer or by an entirely different method of figuring. I cannot impress upon you too earnestly the importance of a thorough check on all work. Without it, mistakes, and sometimes serious ones, are sure to occur, for the man who makes no mistakes is the man who does no work.

Some students of technical schools look down upon drafting as being *infra dig.*, and think it not worth while to perfect themselves therein, assuming that immediately after graduation they will obtain positions outranking those of draftsmen. No greater mistake than this can be made. If any of you have gone through school with this idea in mind, I advise that before beginning actual practice you take a post-graduate course in the mechanical part of drafting. It is by no means enough to know how to outline a design; it is absolutely essential that you be able to finish the drawings neatly and thoroughly, so that the blue prints made from your tracings will be a credit to the office where they were prepared. Drafting is by no means beneath the dignity of an engineer, and unless he be truly proficient therein he is likely to fail to attain success.

This reminds me of an amusing incident that occurred the other day in my practice, so I shall relate it as an illustration of the point I am trying to make.

A middle-aged engineer of considerable experience but who was temporarily out of work, applied to me for a position in our office, volunteering several times the information that he was an engineer and not a draftsman. He dwelt so much upon this point that I felt constrained to inform him that nearly all the draftsmen in our employ were engineers and several of them very good ones indeed. Although sadly in want of office assistance, we had no position to offer the gentleman.

There is no part of an engineer's work that is *infra dig.*; and I assure you, young gentlemen, that there are many valuable things which you can learn from the illiterate workman who labors in the ditch with his pick and shovel, or who mixes concrete on the platform. There is no part of construction work that is of too menial a nature for you to learn. Knowledge of every kind will stand you in good stead sooner or later. There is a certain amount of drudgery that all have to do, and it should always be done willingly and good naturedly. The harder you work on it, the sooner it will be finished; therefore get right at it and do not shirk.

Every young engineer should make a practice of reading the leading technical papers, at first covering almost the entire practice of engineering, but gradually omitting those articles in which he is not peculiarly interested, until finally, after his specialty is chosen, his reading will cover only the items of general news and those papers which pertain to his particular line of work and thought. One must discriminate in reading of all kinds, for otherwise much valuable time will be wasted. There is certainly a deal of technical trash written; so it is necessary to learn how to separate the wheat from the chaff.

Are some of you congratulating yourselves with the thought that your four years of hard study are at last over, and that after you enter the actual practice of engineering there will be no further need for study? If so, please proceed at once to disabuse your minds of this idea, for it is fundamentally and essentially wrong. If you fail to keep up and to carry on your studies, good-bye to all hopes for professional distinction or even mediocre success. Engineers have to be students all their lives, and the younger they are the greater their necessity for studying from books. Believe me, you have still a great deal to learn; so I advise each of you to devote at least one hour per day, or preferably two hours, to the continuation of your technical studies and to the reviewing of your mathematics, both pure and applied. The day when you will no longer be able to continue such studies will come only too soon; consequently I counsel you, while you are still young, to devote to them what time you can spare.

Lay out in consultation with some professional friend a course of study in both theoretical and practical subjects, and stick to it conscientiously. Set a certain time for a certain amount of reading, and if you fail to cover it in the given period, work harder in the next period so as to catch up with your programme. No matter what your occupation may be, you will be able to find time for study as long as you continue to be an employee, because no employer can expect to occupy more than a reasonable amount of your time in excess of the usual hours of labor, even if he do compensate you for it with extra pay.

Study well the English language and obtain a thorough command of it, in order that you may be able to speak and to write it with conciseness and vigor. Perfect yourself in style by reading well written books, even if they come under the denomination of light literature. A little of the latter affords relaxation, and, when really good, can do no harm to a professional man, unless he become so addicted to its perusal as to neglect more important reading. Nowadays there are many American and Canadian writers of good fiction, whose command of the English language is excellent, so there are plenty of good, interesting books from which to choose.

As a rule the graduate engineer has no time to devote to the study of foreign languages; and it is questionable whether it be advisable to devote to them much time at the technical schools. The plea for their retention is that there are many good technical books in these languages that the student ought to be able to read. My reply to this is that there are more good technical books in the English language than a man can ever find time to study, and that all valuable technical works in foreign languages are soon translated into English. In my opinion, a knowledge of French is only a gentlemanly accomplishment, and one that a man is very liable to lose for want of use, and a knowledge of German is of no advantage whatsoever to an American engineer. There is one foreign language, though, that I believe it would be good policy to teach to technical students, and that is the Spanish; but the instruction given in it, to be of any value at all, should be so thorough as to enable each student to read, write and speak it with ease and fairly correctly. Is such a course practicable? I answer most decidedly, "yes," but the methods of teaching foreign languages now in vogue in technical and most other schools would have to be abandoned and a more practicable method substituted instead. The reason for teaching Spanish in technical schools is that American engineers are beginning to monopolize the principal engineering positions in the Latin-American countries; and, as the latter develop, the demand in those countries for American engineers will surely increase. A man going to such a country without any knowledge of the Spanish language is badly handicapped. Eventually he will learn by contact enough of it to get along; but owing to lack of time for study and the unavoidable disability of advancing years, he will never be a master of even the rudiments of the language. It is far easier for a boy to learn a foreign language than it is for a middle-aged or elderly man. Concerning this matter I am speaking from experience, because for the past three years a large percentage of my professional work has been located in Mexico and Cuba, and I have spent fully one-third of that time in the former country. How often have I wished that I had studied Spanish properly in my youth instead of wasting my time on Latin and Greek, both of which I have long forgotten!

In laying out a course of post-graduate study, be careful to choose only those subjects that will have a practical value, and beware of abstruse mathematical calculations, for these too often are based on false hypotheses and in consequence produce unreliable results. Mathematics should be treated as a servant and not worshipped as a god! Some men appear to think that a technical paper, to be of any account, should be filled with abstruse mathematical calculations, on the same principle which many old English writers adopted when they interlarded their writings with numerous Latin and Greek quotations, simply to show that they had received a polished education. This is all wrong; for the less mathematics a technical paper contains and the simpler the mathematics, the better, in my opinion, is the paper. Now don't go off with the idea that I am not a believer in the higher mathematics and in the necessity for their study. Although as a rule the mathematics in an engineer's practice are of a very simple and elementary character, yet there occasionally occurs a problem which will set him to thinking and to brushing up on the mathematics of his school days. It was only a few weeks ago that I ran across one of these cases, and I shall now describe it to you in order to illustrate a practical man's habit of making short cuts to obtain results.

From a point on a bridge tangent out in a river, three hundred and forty feet from its intersection with a base line which cuts it at an obtuse angle, starts a twelve-thirty curve. The problem was to locate exactly the intersection of the curve and the base line. I made several attempts by both trigonometry and analytics to get an exact equation, but each time found that I had too many unknown quantities for the number of my equations, so while I was thoroughly convinced that an exact, direct solution of the problem was feasible, for lack of time I simply fudged it by establishing an equation of only one unknown quantity, viz., the angle included between two radii of the curve, one passing through the starting point and the other through the intersection of the curve and the base line. One side of this equation involved the sine of this angle and the other side the cosine; so by measuring the angle very accurately on the plot and making three or four trial substitutions in the equation, I was able to obtain its true value with all the necessary accuracy. I had given the problem to one of our assistants, a very bright young fellow who graduated last year from the Industrial University of Arkansas (an institution, by the way, which has turned out two or three engineers who are second to none in their specialties); and he by taking plenty of time succeeded in finding the exact equation, but it was an appalling one. Both equations were used in preparing the construction diagram, and afforded an excellent check on the correctness of the calculations.

Let me give you another example of practical mathematics. Several years ago we had occasion to send as transitman on the construction of a large bridge a young engineer new to our employ. One of the first difficult problems that he encountered was the daily determination of the various errors in position of a pneumatic caisson during the process of sinking. The mathematical problem was too much for him, so he telegraphed to our office for a demonstration. My partner replied that I was then on my way to the bridge site and would give him the information desired; so upon my arrival I found the problem awaiting me. Hitherto I had left to my resident engineers the task of ascertaining daily the position of each caisson; and they had always solved the problem by some means or other in a manner satisfactory to themselves; consequently I had never before had occasion to demonstrate the method. I asked the young man to let me see his figures, and found that he had accumulated a mass of sines and tangents of the utmost complication without obtaining any result; so I sat down and worked out in an hour or two a practical solution, then handed it over to him to check. He did not get very far with his figures before he exclaimed, "Here, this is all wrong. You have assumed two lines as parallel when they are evidently not so; for if they were, there would be no error in the direction of the horizontal axis of the caisson." To this I replied, "Yes, I know the two lines are not truly parallel, but how much error have I made in the demonstration by assuming them so? Moreover, granting that the lines are not even approximately parallel, the erroneously calculated error of position will be close enough for an approximate correction during the next day's sinking, and in your next solution of the problem the effect of the false assumption will be almost infinitessimal." Since that time all our resident engineers have been furnished with blue prints containing this "faulty" mathematical demonstration; and some day, when I have time, I am going to insert it in a second edition of De Pontibus.

It is strange what a distaste practical engineers develop for long and complicated formulæ and for making intricate mathematical investigations. This is an excellent reason for giving in technical schools thorough courses in both pure and applied mathematics, and for young engineers to continue their mathematical studies after graduation.

Every engineer should keep constantly in his pocket a note-book in which to record, as soon as he thinks of them, things to be done; and whenever he runs short of work, even for a few minutes, he should look over the list and pick out something that he can finish during the interval. As soon as one of the items has been attended to, he should draw a line through it; and when the list gets too long and too much scratched, he should transfer the remaining items to a new list and start afresh. It is surprising how much can be accomplished in this way. Some people claim that this habit is absolutely destructive to one's memory. This may be true; but it is a fact that a busy engineer's memory is the most unreliable feature in his entire constitution; so the damage done by the note-book is of little consequence.

One should endeavor to utilize all his spare time in either work or amusement, as time simply idled away is an absolute loss to both oneself and the public. An engineer should not even understand the expression "to kill time." As I often tell people who delay me unnecessarily by failure to comply with instructions, "Time is the most valuable thing I possess, and you have robbed me of some of it by not doing as you were requested." Even when traveling one can utilize his spare time; for example, this address was blocked out on a Pullman car and written in hotels during a business trip in the South about a month ago.

It is an excellent plan for an engineer to keep a diary and record therein daily (not weekly or even on alternate days) all events of importance, work done, progress of constructon, etc. Such a diary will prove of great service in many ways, especially on field work.

Every young engineer should join the leading technical society in his branch of the profession, starting in as Junior immediately after graduation and changing grade as soon as he qualifies, until he reaches the highest. He should also take an interest in the Society's affairs and contribute to its proceedings by writing for it papers, either descriptive of his work or recording the results of original investigations or compiling scattered knowledge. Don't write until you have something interesting and valuable to present; but make it your business to find something of the kind as soon as possible.

It is a good thing for a young engineer, after he has been from three to five years in practice, to spend a year or two in teaching engineering in a technical school, for no experience can impress things on one's mind so thoroughly as does teaching; besides, a year or two thus employed offers the young engineer an excellent opportunity to make investigations based on his practical experience, thus contributing to the general fund of professional knowledge as well as aiding to establish his reputation as an investigator and a technical writer. It does not do, however, to spend many years at teaching, unless one intends to make it his life's work. No greater mistake can be made than to start teaching in an engineering school immediately after graduation. The newly-fledged alumnus is fit to teach no part of the curriculum, unless it be pure mathematics, and he could teach even that much better after having had a few years of practical engineering experience.

Every engineer who has any literary gift whatsoever should cherish the ambition to write a technical book. Good technical books are needed today, and will always be in demand. Their lives are of necessity short, as practice is constantly changing; but the fundamental principles of design and construction never change; so he who deals with these in his writings will produce works that will continue to be useful perhaps long after he has passed away.

In your practice do not hesitate to try new methods or to depart from established custom, provided that after thorough consideration you feel sure that the departure would be a wise one and in the line of improvement. If all engineers followed precedent, how little progress would be effected! Should you, peradventure, come to grief in any of your experiments or departures from the beaten track, don't try to hide your failure, but publish it generously so that others may be warned by your experience. Believe me, the confession of such a failure will not harm you in the least, but will give others confidence in your honesty and courage.

In all that you do remember that you have the reputation of the greatest of all professions to uphold, that your integrity must ever be beyond question, and that there is never an excuse for untruth of any kind. Business shrewdness is all very well in its way, especially for those who go into contracting; but falsehood is always needless. On the other hand, an uncompromising bluntness is unnecessary; and, in dealing with people, a cultivation of policy and tact is a virtue. Because you think a man is a fool that is no reason for telling him so; and, when you see that an individual is cherishing some pet notion which is erroneous, it is far better to lead him gently to a recognition of his error than it would be to tell him imperiously that he is wrong, or that he does not understand the matter. Policy and tact are just as essential to success in engineering as are ability, energy, and integrity. By means of the last three attributes one is enabled to do his work thoroughly and well, but it takes the two former to enable him to secure it.

Never repudiate a promise or engagement of any kind, but perform what you have agreed to do, even at pecuniary loss to yourself. If you adhere strictly to this rule, it is evident that it will be necessary for you to beware of making rash or hasty promises.

I had intended speaking to you at length upon the subject of engineering ethics, but time will not permit. It is a matter which is still in embryo. We have no established code of ethics in our profession; so, until the solons who are now discussing the matter decide upon one, all that an engineer can do is to treat squarely everybody with whom he comes in contact, to try to make others happy whenever it is possible, and always to act according to the dictates of his conscience.

No matter how small your earnings may be, always endeavor to save and put in bank a portion of them, for the money thus saved will assuredly prove useful some day. Avoid fancy investments of your savings and dabbling in projects that promise enormous profits. They nearly always fail, and the money invested is usually all lost, with occasionally considerably more. Engineers do not make good investors, because their attention is so devoted to their profession that they fail to obtain the necessary experience to care properly for their possessions. It is far better to invest in good first-mortgages or even government bonds than to sink your earnings in the most promising of schemes. In this matter heed the advice of one who speaks from sad experience.

If one is in the employ of a good, substantial, manufacturing or contracting company, it is well to invest at least a portion of his savings in the stock and securities of that company, especially if these be offered at a low figure as an inducement to the young man to take an interest in his work. Such an investment tends to the employee's advancement, and may eventually lead to a high official position. An excellent example of the good effects of such a system is given by the Carnegie Steel Company, most of the present officers of which started in at the bottom of the ladder in the company's employ, and worked their way up by becoming stockholders. In spite of all the talk one hears about soulless corporations, good, efficient, faithful, and willing service is nearly always recognized and retained; so I would by no means discourage any young engineer from working for a large manufacturing company which employs civil engineers.

Make a practice of studying true economy in your designing. It is far better to build a structure which is cheap and has no pretensions to permanency, rather than a quasi-permanent one that is cheapened by ignoring the first principles of design, and that will surely wear out or fail sooner or later on this account.

The writing of specifications is one of the most difficult tasks that you will encounter in your practice. At first it will be best for you to adopt, if possible *in toto,* the standard specifications of older engineers, or use these as a guide in preparing your own, until such time as you can produce some which will be better than any others. Don't make changes, though, for the sole purpose of producing something original, but only for the sake of effecting improvements. Specifications should be clear, concise, complete and free from all unnecessary repetition.

Study the science or art of systemization, for it will aid you materially in your practice. If it be not improper in an address of this kind for the speaker to quote from one of his own published works, I would like to repeat the following from the chapter on " First Principles of Designing " in my " De Pontibus ":

"The systemization of all that one does in connection with his professional work is one of the most important steps that can be taken towards the attainment of success."

If you have the opportunity, do not fail to take post-graduate degrees or any other degrees or professional distinctions that are within your reach. They cannot possibly do you any harm, are a source of great satisfaction to the recipient, and carry weight with most of the men that one meets.

I may get into trouble by stating it, but I am firmly convinced that early marriage is not conducive to a successful career in engineering, for the reason that it confines a young man too much to one locality and causes him to strive for the almighty dollar rather than for ultimate professional advancement.

And now before closing there is possibly an apology due my hearers for the marked personality of this address. If so, please consider the same made most truly and humbly. In writing it, I felt that I could get nearer to you all by referring occasionally to my own experience, dropping all formality, and speaking from the standpoint of a brother engineer, nor do I think that I have been wrong in so doing; nevertheless I would not be surprised if I be criticised adversely for this, especially if my address appear later in print.

By this time you all have probably come to the conclusion that you have been listening for the last half hour or more to an old fogy, who thinks that there is nothing in life worthy of consideration but work, work, work, and who can talk on nothing but technical subjects. If this be so, I by no means blame you, for you would seem to have reason on your side; nevertheless you would be entirely in the wrong, because I am a firm believer in legitimate relaxation of every kind and in a man's getting all the pleasure he can out of life. Perhaps, too, I could talk of things that are far from technical, such as hunting the great game of the Rocky Mountains, canoeing on lake and stream, the shooting of rapids, travels in foreign countries, gunning for wild fowl in the marshes, sports afield with dog and gun, fly fishing for trout in the streams of the far North, and struggling with the gallant tarpon on the waters of the Gulf of Mexico; but it was not to discuss such subjects as these that your President brought me here, so I shall desist, only remarking that the more you mix these things and other sports and amusements in with your work, the better will it be for you both physically and mentally, the longer will you live, the more will you accomplish, the more satisfactory will be the results of your work, the better men and citizens will you become, and the more interesting and agreeable will you prove to all with whom you are thrown in contact.

Certainly mine has been a decidedly rambling discourse; but I hope you will pardon this feature of the address for the reason that "scattered shot hits most birds," so perhaps I have bagged several of you with some of my pellets; while, had I used a choke bore by adhering steadfastly to one subject, I might have missed my aim altogether, or at best succeeded in capturing only one individual.

In conclusion I beg to say, gentlemen, that it has given me sincere pleasure to meet and address you; that if in the future I can serve you either collectively or individually, I shall be at your command; that I hope some of my remarks may some day prove of benefit to you, and that I wish for each one and all of you the greatest satisfaction in life—a truly successful, professional career.

COMMENT.

One of the greatest dangers the young engineer encounters is that of falling into a rut and permitting precedent to govern him. Action without careful consideration, haste in expression of opinion, and failure to give due attention to what has already been done, produce results which are far from desirable, but the sluggishness which springs from extreme caution greatly limits the young man's usefulness, makes him a slave to precedent, and results in mediocrity. Every well-advised attempt to do original work is a step in the right direction, but the advice of the experienced engineer upon the choice of subjects for investigation will be of great service. Much effort is wasted on work which has already been well done, hence no original research of moment should be undertaken before all available technical literature has been examined for what has already been published upon the subject. The opinions of older engineers relating to the value of the contemplated investigations should also be sought. These precautionary measures are in themselves a source of much information, and they will insure that the work is spent upon a meritorious subject.

The desire to produce something original and noteworthy should, however, be restrained until much and broad reading has been done. The recent graduate has only cultivated a very limited portion of the field. Many subjects of large importance have been wholly ignored in his course of study and in the collateral reading he did while in college. The best books on these subjects should be purchased and thoroughly mastered as rapidly as possible, and the technical papers should be watched for reviews of new works, works relating to these lines as well as to those which are already familiar. The reviews are commonly prepared by engineers or professors of standing who are specialists in the branches of which the books treat, consequently, they are ordinarily dependable. Several books on each subject should be read, as writers not only have different opinions, but some give more attention than others to particular phases of the subject; thus the reader gains in thoroughness by repetition and devolops well balanced views of the whole matter.

The technical papers pass in review all branches of engineering and thus give an excellent idea of their importance and relations. It is unwise to draw conclusions from a single paper, however, for some of them are biased in favor of one line of work and give it attention which is out of proportion to its importance.

In reading technical papers, the advertisements should receive quite as careful attention as the reading matter proper, for they constitute a very valuable source of information relating to the progress in invention and manufacture and often in methods of design and construction. They also do much to broaden one's general knowledge of manufacturing companies and their personnel.

The reading should by no means be confined to engineering literature, though that should undoubtedly be given the preference. Books relating to pure science are especially valuable, because they supply useful data, quicken the perception, broaden the mind, and illustrate methods of scientific investigation. Books of travel broaden the view. Poetry, history, fiction, and philosophy stir one's interest in life and in one's fellows, tend to make one more a man among men, and remove the danger of becoming a pure technist. They also improve the English and give a greater command of language.

The better reviews assist one in keeping abreast with the thought of the world, but much of their contents is of only transient interest. Too much attention to them takes time which should be devoted to more substantial matter, but such papers as The Nation, Public Opinion, and The Outlook epitomize current literature and save much labor. Too much time devoted to newspapers is not fruitful and encourages lazy habits of thought.

No amount of reading, however, will take the place of personal examination of structures, machinery, and methods of construction; and the opportunity to visit engineering works should never be passed over. A superficial examination is not enough. It is essential to grasp the broad, general ideas of construction, but acquaintance with them is of small value unless it is supported by a knowledge of details.

Neither will an intimate knowledge of pure literature serve instead of contact with one's fellows. The engineering clubs and societies are exceedingly valuable in bringing together men engaged in the same lines of work for a free interchange of ideas. Even the non-resident member gains much from the written expressions of opinion.

The immediate work in hand should be left at the office, unless it be so urgent that it is necessary to work overtime, but points of interest relating to it should be given attention in the spare time. As a general rule, however, it is best to obtain the needed rest by devoting the leisure hours to the study of subjects related distantly, if at all, to the daily work.

These matters are all aside from the engineer's regular work, but they form a large part of his life and exert a great influence upon his progress.

Hard work is essential to success, but does not assure it. The successful engineer must be an exceedingly broad man, well versed in business, sound in his views on financial matters, well grounded in the law of corporations and of business relations, and, though modest, confident and firm in his position. Hence the young engineer should avail himself of every opportunity to gain a sound knowledge of business. It is not enough to understand his immediate duties; in fact, when he finds himself thoroughly informed regarding the work he is doing, he should seek other fields where he will learn new lines of work and thus lay a better foundation for the future. He must always be on the alert for new data. Everything which is important in itself, no matter what may be its relation to his work, will sooner or later be valuable.

The effort to gain a broad knowledge of engineering matters should be guided by a definite plan; otherwise, the information will be fragmentary, and action based upon it will be more or less uncertain. It is a good plan to consider one line of work at a time and exhaust all available sources of information relating to it before taking up another subject. For instance, reinforced concrete construction is now attracting a large share of the attention of engineers. The literature of the subject is fragmentary; much that has appeared in the technical periodicals is unsound; books relating to it are few; consequently, the young engineer who lacks experience but wishes to be sound in his views must read the most of what has been printed and read it cautiously and judiciously. To read casually or to study a single work on the subject will result in the half knowledge that is dangerous.

Dr. Waddell's suggestion that the young engineer knock about for several years, staying in one place only so long as he can learn with satisfactory rapidity, is excellent advice. However, to change positions without obtaining a change of work is generally a detriment rather than a benefit. To go from the drafting room of one bridge shop to that of another which does the same class of work is the way to become a tramp draftsman, not an engineer; but to go from the drafting rooms of one company to the designing rooms of another, or from a shop which fabricates buildings to another which devotes itself to bridges, is a step in the right direction. It is hardly necessary to say that the common practice of following one narrow line of work continuously because the largest salary is to be obtained by doing so results in narrow experience and decreases the chances of rising ultimately to a high position. Specialization, to be effective, must be preceded by broad, general experience.

Too much emphasis cannot be placed upon the value of thoroughness in all one does. A young man's official superiors are constantly searching among the rank and file of the young engineers for those who are fit for promotion, those who are fitted to take up some special branch of the work, and those who possess executive ability. And it should not be forgotten that no one can satisfactorily direct others who does not possess a thorough knowledge of the work himself. The half-hearted, indolent habit of guessing, of doing work without understanding it, and of slighting details stands in the way of many a bright man's advancement. It is infinitely better to be slow and thorough than to be quick but inaccurate. Employers soon forget how much time satisfactory work required, but expensive errors stick in the memory. It is exceedingly rare for the graduate engineer to lack the ability success demands, but the absence of the purpose and the energy to do everything well, to master every new problem as soon as it arises, and to give careful attention to details is frequently responsible for both failure and mediocrity.

The business and prosperity of the country are already largely dependent upon the engineer, and his importance continues to increase with great rapidity. Economic advancement is in his hands. His discoveries and inventions cause new lines of business to spring up over night. The expenditure of incalculable sums depends upon his judgment. The convenience, the comfort, even the lives of the multitudes are under his control. The responsibility of the engineer, individually and collectively, is enormous, consequently, he should be a man of high ideals and of unquestioned integrity. No compromise of any kind may be countenanced. His high position is dependent upon his honesty, his fairness, and his trustworthiness; hence he should not deviate in the smallest measure from the path of strict rectitude.

It is the duty of every engineer to assist his brother engineers to the full extent of his opportunities. A slight service, a suggestion, a bit of advice, will often yield enormous returns. The satisfaction arising from a kindly act is in itself ample compensation, but the kindness or assistance is generally repaid with usurious interest, possibly years after it is rendered. The friendship of the older man gives the young man confidence in himself and encourages him in his dark periods and frequently keeps him in the right path, while the esteem and good will of his fellows is warmly returned in kind.

ADDRESS

BY

J. A. L. WADDELL

TO

THE ENGINEERING STUDENTS

OF

THE MISSOURI STATE UNIVERSITY.

APRIL 2, 1903.

INTRODUCTORY NOTES.

The succeeding Address to the Engineering Students of the Missouri State University was written and delivered early in 1903, consequently it bears evidence of its author's wide experience with young men just entering practice and contains a great many suggestions which are well worthy of any student's careful attention. Few lecturers, especially few men of sufficient years to attain prominence, are able to address students without talking down to them and thus forfeiting their confidence. If a lecturer evidences a patronizing spirit or manifests the effort to make matters clear, the student resents the lack of confidence in his understanding, and in a large measure the lecture fails in its purpose. His experience, both in teaching and in lecturing, and his pronounced interest in students and young engineers have enabled Dr. Waddell to avoid these faults and with rare tact to render his ideas clear and acceptable to the student. The earnestness and vigor with which his ideas are expressed are in themselves sufficient evidence of his good faith and his sympathy with his hearers.

The chief value of an advisory discourse for under-graduates lies in the cause of immediate action it provides. The student too frequently looks upon the advice his instructors give as their method of bending him to their will, hence advice which comes from a disinterested source is given more attention, both because it is disinterested and because the advisor is known to be a successful practitioner and, consequently, one whose opinions are to be respected. The more earnest students have the possibilities of the future constantly in mind and welcome any suggestion or any glimpse of what will be expected of them in practice.

The cause of engineering education would be materially advanced if more practicing engineers took enough interest in it to give their time and knowledge in lectures at institutions with which they are acquainted. Even informal discussions, illustrated as much as possible, will aid instructors materially in sending out well equipped, earnest, energetic graduates.

TO THE UNDERGRADUATES OF THE ENGINEERING DEPARTMENT OF THE MISSOURI STATE UNIVERSITY.

Young Gentlemen:

When the Secretary of your Engineering Society requested me to lecture to you, I agreed very gladly and asked whether he would prefer an address consisting of some practical advice to undergraduates or a talk on some branch of my specialty. His answer was that you would appreciate better the advice; consequently I have arranged to give this to you to-night; but I am prepared also to give you afterwards, if you so desire, one or two talks on bridges. They will be essentially extempore and of a very informal character, and will be illustrated by numerous blue prints and a few photographs, the most of which I shall be happy to leave with your professor of civil engineering, if he care to use them in his class work. As these technical lectures will be most uninteresting to all except those who have either studied the subject of bridges or intend to study it, I would suggest that my hearers be limited to such students; more especially because the illustrations are on so small a scale as to make it inconvenient for many persons to view them simultaneously. My time for the next day or two will be entirely at your disposal; therefore, if, when I have finished addressing you to-night, you will arrange the time and place for us to meet again, I shall endeavor to present to you then, under the title of "The Most Approved Types of Modern American Railroad Bridges," a simple and concise statement of the present status in this country of bridge engineering and construction, together with an historical sketch of the development thereof.

And now to the matter in hand:

Of late years the addresses of this character that I have made have been presented to graduating classes, and, in consequence, they have had special reference to the early professional life of the young engineer; but to-night I desire to speak to you mainly concerning your course in the University and your undergraduate life.

If, upon the conclusion of my talk, you are not utterly wearied, but are desirous of receiving further advice that will apply to your careers after graduation, I shall be pleased to offer you later the substance of an address that I made last summer to the graduating class of the engineering department of the Rose Polytechnic Institute.

Were there any probability of your having read that address, I should hesitate to offer to give it again, but you are not likely to have run across it; for as far as I know, it was published only in a local paper of Terre Haute. Moreover, I said on that occasion about all that it is necessary to tell you concerning what, in my opinion, is best for the young engineer to do in order to succeed in his profession; hence there would be no use in my preparing for you another lecture on the same subject. Besides, if I did, I would simply repeat myself.

In treating of the work of undergraduates, I fear I am treading on delicate ground, because it is possible that I may say something which will conflict with the ideas and practice of your worthy professors of civil engineering. If so, I beg to apologize in advance and to state that my offence ought to be excusable, since I know practically nothing about the engineering course given here.

Any criticism that I may offer about engineering education refers to such education in general and applies to no particular institution of learning.

This possible trouble that I may get into reminds me of a rather amusing incident of my early professional days.

In 1878 I acted for a short time as chief engineer of a coal mine in West Virginia. I say "chief" advisedly, for I had two assistants, one white and one black, but neither of them could read or write, except that the colored man could make out the figures on the tape line. After a few months I was offered another position more to my taste, accepted it, and tendered my resignation to the owner of the mine, who very kindly expressed his regrets at my leaving, saying also, "The miners, too, will be sorry to have you go, for you have become quite popular among them." This took me all aback and I replied, "That is very strange indeed, because for the last three months I have been most outspoken in telling them all what blooming idiots they are to countenance strikes." To this the owner of the mine replied, "Oh, that is all right. They attribute it simply to your ignorance."

Hence, if in this address I make any *faux pas* or tread on anyone's toes, I hope that, like the miners, you will excuse me and "attribute it simply to my ignorance."

In the old days when I was a student—something more than a quarter of a century ago—the general impression among undergraduates appeared to be that they ought to study just enough to pass and no more; that their instructors were their natural enemies, whose business it was to find out their weak points and to condition them if possible, and that to hoodwink a professor into believing a student knew something that he did not know was the highest possible achievement in student life. Such a state of affairs was due to a variety of causes, among others the following being prominent:

First.—The idea entertained generally by the faculty that graduation from an engineering school of high standing ought to be a case of "survival of the fittest," and that none but men of high attainments as students ought to become engineers.

Second.—The admission of boys instead of young men into engineering schools.

Third.—The employing as professors, to teach engineering subjects, men who were mere theorists and who had never had any actual experience in either office or field.

Fourth.—The erection and maintenance of an artificial barrier between professors and students, which prevented them from meeting on common, professional ground.

This spirit of conflict between professors and students is fundamentally wrong, as is also the idea that a student should study merely enough to pass the examinations. Fortunately for the engineering profession, these false notions are rapidly becoming obsolete, although I note occasionally in my travels that the same old antagonism and want of confidence still exist to a certain extent in some of the technical schools. A professor ought to be his students' best friend, not only during the time he is instructing them, but also throughout his entire life. He should regard them almost as his own sons and should encourage them to turn to him for advice or assistance whenever they feel the need of aid in their professional careers or when discouraged by the world's hard knocks. Nor should he wait for his old students to come to him for assistance, but should do his best at all times to push their fortunes and advance their standing in the profession by saying, whenever occasion offers, a few good words for them to the older engineers and to any other individuals with whom they are likely to have business relations.

Again, the notion that only ideally fine students can become good professional men is entirely erroneous. Many a slow-thinking student who has either been dropped from his course or just managed by great effort to pass the examinations and take his degree has become a successful engineer; and it is well known that many of the finest mathematicians who graduate from technical schools are never heard from afterwards in the engineering world. Now do not go away with the impression that I believe it is not the good students who make the best engineers; for on the whole, they most decidedly do; but I maintain that some men who as students think slowly and acquire knowledge with difficulty, after leaving the technical school develop slowly but surely into sound, trustworthy and high-class engineers. In dealing with such students, the professor should not let their slowness hold back the brighter and quicker men, but he should devote to them more of his personal attention, aid them in thinking more quickly, and force them to keep up with the class. If such men are possessed by a great desire to succeed, the assistance thus given them will generally put them through the course in fairly good shape; but if they are not, the sooner their names are dropped from the rolls the better.

Some of you may be thinking that these last few remarks of mine are better fitted for an assemblage of professors than for one of technical students. Perhaps they are; nevertheless some of you may some day become professors, and in that case the remarks are apropos. At any rate they must not be construed as in any way reflecting upon the professors at this institution.

I am glad to note that of late years the average age for entering engineering schools has increased by a year or two. In my class at Rensselaer, the average age for entrance was seventeen and a half years—exactly, by the way, my own age at that time; but now I understand that the average age of entrance for all the technical schools of the country is about nineteen years—however, I may have been misinformed. In my opinion, the proper age for entering the freshman class is between eighteen and twenty; at less than eighteen one is too young to appreciate the course fully, and entering when over twenty will shorten a man's working time too much; besides, if one starts very late on his life's real work, he is apt to have formed the habit of depending too much upon others for the necessaries of existence, so he will feel rather disinclined to earn his own living, and will be dissatisfied with the character of the living he obtains when compared with that to which for so many years he has been accustomed.

Again, the time is coming when a first-class course in civil engineering will demand five years instead of four. Some sixteen years ago in a paper on "Civil Engineering Education," I advocated strongly a five years' course in civil engineering and made an outline of what should constitute it, stating that a thorough course on the subject could not be given in less time. At present, so far as I know, there is no technical school which gives more than a four years' course in engineering; but for several years McGill University, of which institution I have the honor to be an *ad eundem gradum* alumnus, has been given a year of post-graduate work, and this work is soon to be included in the regular curriculum by increasing the length of the course to five years. When this is done Canada will lead the United States in civil engineering education, and in truth the course in engineering given at McGill to-day is almost, if not quite, on a par with the best course given in this country.

If any of you have an opportunity to take a post-graduate course of a year or two at some first-class technical school, so as to continue your engineering studies beyond the confines of the ordinary curriculum, by all means avail yourselves of it. The time thus occupied will be well spent and you will never have occasion to regret such an expenditure. During such a period you will be almost your own masters and will be free to work when and on what you choose.

It is an excellent plan for a boy who contemplates following the profession of civil engineering to spend a few years at college taking an Arts course, and if time permit, the degree given at its conclusion before entering a technical school; but in such a case he should elect to take as many of the science studies as possible, and to omit entirely the dead languages and most of the living ones.

The study of the dead languages is a relic of the dark ages and clings to our institutions of learning as rigidly as did the Old Man of the Sea to Sinbad the Sailor; yet most of the time spent by engineering students in the study of modern languages is totally wasted. This is for two reasons; because, first, not one in ten learns any more about them than merely enough to pass the examinations; and, second, even if one should learn a modern language well, he would have no practical use for it in the United States; consequently, in my opinion, the time devoted to its study could be used to far better advantage on something of a more practical nature.

The plea that is generally made for the study of modern languages in engineering schools is that there are so many good things in French and German scientific books of which the young engineer would be deprived did he not study these languages. To this plea I beg to reply as follows:

First.—There is very little in either language that would be of any practical value to American engineers.

Second.—That if occasionally a useful article or treatise does appear in French or German technical literature, it is very soon translated into English.

Third.—There are already more good engineering books in the English language than one can find time to read.

Fourth.—And finally, not one student in fifty at an engineering school learns a modern language with sufficient thoroughness to translate or even properly to comprehend a technical paper written therein.

The only foreign language which would be of any practical value to an American engineer is Spanish—and the technical schools do not teach that.

Instead of worrying the students' brains with Latin, Greek, French, and German, why not give them thorough instruction in English, so that they would all become truly masters of their own language? What percentage of the graduates from engineering schools are well posted in English? How many of them can spell correctly? How many of them can write a proper letter? Alas! the percentage is indeed small. Of this I constantly have ample proof in the applications for work that we receive from recent graduates.

Again, I do not believe that the English language is taught properly to engineering students. Too much attention is given to the study of the works of old writers and their antiquated diction, while no time is spent in teaching the young man how to express himself clearly, tersely, and emphatically. Moreover, why spend a lot of time studying and analyzing poetical works? It is plain, every-day prose, not poetry, that the engineer has to deal with in his life's work; and, believe me, there is nothing which will be of greater advantage to a good engineer than a thorough, practical knowledge of his own tongue.

In giving the various courses in English (and I believe they should be distributed throughout the entire four or even five years), why not adopt for some of the examples of standard literature works of American engineers that are written in good English? It is engineering reports, specifications, papers, and books that the engineering student is likely to write after graduating, not novels, or poetry, or books of travel.

How few engineers can prepare a truly first-class specification! The writing of specifications is an art and therefore ought to be cultivated; but, unfortunately, all the engineers of my acquaintance who indulge in the preparation of such literature have had to learn the art after graduation and by means of many hard experiences. Experience is certainly a good teacher, but it is a costly one, and there is no reason why a young man leaving a technical school should not be thoroughly grounded, not only in the elements of specification-writing, but also on the finer points of it.

If there be time within the next few days, and if you so desire, my assistant, Mr. Ash, would be pleased to give you a short talk on the preparation of engineering specifications.

There is one feature of college life which I cannot commend too highly to engineering students. I refer to the literary, debating, and scientific societies that flourish in some of the larger technical schools. These should receive every encouragement from both professors and students. The training that a young man imbibes from debating and from writing and reading papers is of more value than most people suppose. By improving his diction and giving him confidence in himself it enables him to hold his own in after life when striving to push his claims. Modesty in an engineer is more often a fault than a virtue.

It is possible to acquire at college a literary taste, although one may never before have shown any ability in that line; hence I advise you to cultivate one, even at the expense of extreme effort.

Let me advise you to study the subject of plane trigonometry so thoroughly that you will be able to use it with as much facility as you employ the four simple rules of arithmetic and to familiarize yourselves thoroughly with logarithms, for as field engineers you will be constantly called upon to employ trigonometric functions and to shorten your computations by means of logarithmic calculations. These are subjects which are very easily forgotten, so it is well for a young engineer when he finds himself becoming rusty in them to refresh his memory occasionally by reviewing their theory and making a few practical applications of it.

To be strictly honest with you, I fear I have forgotten almost all I ever knew about logarithms, as it is a number of years since I have had occasion personally to apply them, such work in my practice being turned over to younger men. It is strange how readily one forgets! However, if a man has ever studied a subject thoroughly, he will never have much trouble in brushing up on it again, notwithstanding a lapse of many years.

Students of mathematics have a false notion that it is necessary for them to learn merely the theory, and that it is useless for them to spend time in making practical applications of it. They think, too, that approximately correct results are good enough; or even if their figuring proves to be incorrect, it is needless to go through it again, because familiarity with figures will come later with practice. This is all wrong and most reprehensible, because it is at school that the young man should learn habits of accuracy and neatness. Without such habits he will never be truly successful nor able to accomplish great things in his profession.

Let me advise you to devote some attention to the subject of triangulation, by reading all there is written upon it, working out some old cases from actual practice, and finally laying out and computing a triangulation system for yourselves. You will experience great pleasure and satisfaction in seeing how closely your work will check. It is almost incredible to what a small amount the errors in triangulation work can be reduced. For instance, on our Fraser River bridge at New Westminster, where the bridge tangent is some twenty-three hundred (2,300) feet long between base lines, two of our triangles checked that distance within two and a half hundredths (0.025) of an inch, the average total angular error per triangle being less than one second. Numerous measurements of base lines and readings of angles, together with the utmost care, are necessary to secure such accurate results as these.

Should you or your professors desire some old triangulation sheets, you may obtain them by sending a request for them to the office of my firm.

Learn to keep records neatly, thoroughly, and systematically. I cannot impress upon you too forcibly the importance of this advice. Systemization of all that one does is the keynote to professional success.

Let me urge you to be thorough in all your mathematical studies; never quit a difficult point until you have comprehended it totally and absolutely. Don't be content with *thinking* that you understand it, but stick to it till you *know* that you do beyond the peradventure of a doubt. The test of your knowledge is your ability to demonstrate the point to another student in such a clear way that he cannot help comprehending it also.

This has been a guiding principle of mine for over thirty years, and I assure you it is a good one.

I recall an extreme case of its application, which may interest you. When acting as assistant professor of rational and technical mechanics at the Rensselaer Polytechnic Institute in 1879, I was saddled with the drafting part of the various courses in descriptive geometry, but had nothing whatsoever to do with the teaching of the theory. One evening about 7 o'clock there came into my room a young sophomore, a Cuban, and by far the brightest man in his class, with whom I was on very friendly terms; in fact, he was then giving me instruction in Spanish. He told me that there were three lines in Warren's Descriptive Geometry in the problem of the cow's horn which he could not understand, and that he would like my assistance thereon; and, of course, I had to undertake the task.

Now "Windy Warren," as we used to dub him, was the blindest writer ever known to the men of R. P. I., and although, as a student, I had studied his books, this particular problem had been omitted from my course. Never before in all my reading had I struck such a miserably blind, knotty case. After I had spent half an hour on it without producing the slightest result on my mental conception, my young friend saw that he had involved me in some hard work, which would be additional to that on which I was employed when he entered my room, and which had to be prepared for the morrow's classes in mechanics; so he expressed his regret at having troubled me and proposed to take his departure.

Knowing that if I let him go with the point unsolved, I would lose my prestige with him as an instructor, I said: "You have brought me this problem, and I am not going to quit working on it until I have solved it; and what is more, you are going to stay in this room until I have discovered the solution, so make yourself comfortable and go on with your study of to-morrow's lessons." He did so, and I continued for hour after hour to pore over those three wretched lines, till just before midnight I solved the problem and demonstrated it to the young man. The next day he was the only member of the class who was able to explain it on the black-board.

Apropos of descriptive geometry, let me advise you to study thoroughly all the courses in this branch of learning, from the elementary plane problems, up through projection drawing, descriptive geometry, shades and shadows, perspective, and stereotomy. It is a beautiful course of study and one of absorbing interest, involving many delightful hours of most satisfactory investigations.

In order to grasp the problems of descriptive geometry and its allied studies, it is necessary for the student to think in space and not upon a plane. Let him imagine the object that is to be portrayed to be located near a corner formed by three rectangular planes and at a short distance from each plane. Then let him imagine his eye removed to a great distance so as to look at the object with lines of sight practically parallel and perpendicular to the three co-ordinate planes. When he can thus see the object in space he will comprehend the theory of horizontal and vertical projections, and can begin to think of how the object would look when intersected by oblique planes, cylindrical surfaces, etc. In this way, and in this way only, will he be able to deal with and handle properly complicated problems in descriptive geometry.

If I were again a student, I would investigate these descriptive geometry branches much more deeply than is done in the ordinary engineering course, for not only would I make many extra drawings to illustrate the problems, but I would also build illustrative models with paper, wood, and threads. Once in a while in our office practice, when engaged on some unusually difficult and complicated piece of designing, we resort to modeling as an aid to a proper conception of the proposed construction. The last time we did anything in this line was in connection with the designing of the spread span of the large bridge which we are now building over the Fraser River at New Westminster for the government of British Columbia. The preparation of this model was entrusted to a young Japanese engineer, Mr. Fujino, who was first a student in our office and afterwards one of our most trustworthy assistants. The model that he manufactured out of cardboard was used by a number of our draftsmen in preparing the working drawings.

Learn how to make good perspective drawings. It is an accomplishment which some day may prove useful, especially when dealing with financial men, who often desire to see what a proposed structure will look like, and who cannot understand projection drawings. As an example of the use of perspective, I shall show you to-morrow two photographs of perspective drawings of bridges made lately by one of our Japanese assistants. That of the St. Charles bridge over the Missouri River was prepared by the request of the project's financiers, and the one of the Fraser River bridge for some of the officers of the British Columbian government.

If you have any natural taste for free-hand sketching, by all means cultivate it, because not only will such an accomplishment aid you in filling out the landscape on perspective drawings, but it will also be exceedingly useful in making pocket-book sketches of machinery, structures, and other objects of interest.

Some young men have an idea that it is a bad thing to be a good draftsman, because one who is expert in this line is apt to be kept at drafting work. Anyone who has acted on this principle would have a very poor chance of obtaining employment in the office of my firm, for we have no use for any engineer who is incapable of making a drawing which will not do discredit to the office. There is no more reason in such an idea as this than there would be in a young merchant cultivating an illegible hand for fear that his employers might confine his services to bookkeeping.

By all means learn to do lettering quickly and neatly. Proficiency in such work will certainly stand one in good stead sooner or later.

You ought to pay special attention to the keeping of clean, clear, systematic notes and records of both field work and office work. This you can do while you are still at school, first, by keeping your field notes in the most approved way, and second, by spending a month or two of your vacations in a large engineering office, where you will be able to study the latest and best methods of filing and indexing letters, drawings, specifications, contracts, etc.

Learn how to prepare and use a card-index; for without one, no engineering office that does great work can be handled to best advantage.

If I were in your place, I would spend almost all of every vacation in doing some actual engineering work, mostly in the field on account of both the health and the experience that are thus to be gained, but also partially in the office. Do not try to earn money on such work, but offer your services gratis, because, as a rule, they are worth very little in the field and less than nothing in the office. If you receive pay, you will probably be kept pretty steadily at one class of work; but if you do not, you will feel at liberty to ask for a varied experience. Moreover, if, when you leave, your employer thinks that you have been of actual service to him and that your work has been of real value, he is likely to present you with some small amount of money as compensation. Remember that in England young men who are studying engineering have to pay large sums for the privilege of working for several years without salary in the employ of prominent engineers. In this country we have not come to that yet, although my partner, Mr. Hedrick, once threatened to establish in our office the custom of demanding initiation fees; for he complained bitterly of being tired of keeping a kindergarten and having the young men leave as soon as they had learned to make themselves useful and had become able really to earn small salaries in the employ of bridge manufacturing companies.

In spite of the many unsatisfactory features involved in training young engineers, we still continue to do so for our own benefit as well as for theirs; because we find that those who come straight from technical schools to our office for their practical instruction are afterwards much more satisfactory than those who come to us after having had several years' experience elsewhere, the latter having so many things to unlearn.

If you spend a vacation in an engineer's office, learn how to write business letters, how to copy and file them, how to keep accounts, and the general routine of the office; and make in your note-book full records of all these things. The keeping of accounts is such an important matter that I would advise your taking a course in bookkeeping before you graduate. This you could do during some of your spare hours. The course need not be very elaborate, but it should be thorough, notwithstanding.

When spending a vacation on field-work, learn as much as you can of the minor details of it and consider nothing *infra dig.* You should be able to shovel concrete, cut threads on pipes, couple up piping, saw timber, fire a boiler and oil an engine, sharpen tools, drive rivets, measure up work of all kinds, and, in short, make yourself generally useful whether you are working in the employ of the contractor or on the engineer corps. No source of information is so lowly as to be despised. A skilled workman or even an intelligent navvy can tell you many useful things which you will not find written in any book. Be ever on the alert to pick up, record and systematize knowledge of every kind that promises in any way to prove useful in your professional career. Study carefully the printed forms and methods of making monthly estimates, progress reports, payrolls, distribution sheets, pile-driving records, etc., that are adopted on large engineering constructions, and obtain for your own future use copies of all blank forms employed for field-work. Learn from observation and by cultivating the acquaintance of those who are experienced in that line how to deal with and handle workmen; and see if you cannot from your own observations come to the conclusion that practical engineering and the science of compromise are very closely allied.

As every energetic man has his fads or hobbies, it is well to cultivate those which are useful; so I would suggest that you go in for amateur photography, learning how to take good photographs, even if you do not develop them yourselves. Daily photographs of construction are a most useful adjunct to progress reports on important engineering works. My firm encourages its resident engineers to take such daily photographs, and we find that it pays us well.

There is one feature, common to the curricula of all the engineering schools in America, which I feel compelled to criticise severely; and that is the failure of the faculty to include in the course of study any reference to the history of civil engineering and its development. In consequence, the graduates are unacquainted with the great engineering works of the past, and do not even know the names of the famous engineers who are dead or of those who are making engineering history to-day.

Let me give you an illustration of this. Some two years ago when traveling I became acquainted with a pleasant young fellow, and ascertained that he was a graduate of one of the leading Eastern technical schools, so our conversation naturally drifted to engineering subjects. Incidentally, I mentioned the name of my friend, Mr. Elmer L. Corthell, as being connected with some large undertaking, but the young man had never heard of him, hence asked who he was. I explained that he was one of America's most eminent engineers, and that he made a specialty of harbor work. I also said that in his younger days he had been the right-hand man of Captain Eads on the Mississippi jetties, but, *mirabile dictu,* the young man had not heard of either Captain Eads or the Mississippi jetty-work. Such ignorance as this is inexcusable, but the young man was not to blame—the fault lay with his instructors.

In order to try to correct this sad state of affairs, I am going to suggest to the Society for the Promotion of Engineering Education that some of its members combine to write a book, entitled, "The History of Civil Engineering," apportioning the task among a number of them by dividing the subject into the various specialties, letting each writer treat independently the history of that specialty, and combining all the resulting papers into a single large volume.

In this way the work of many able men of both the past and the present would receive merited recognition, the engineering profession would obtain some most interesting and enjoyable reading matter, and the young fellows turned out of technical schools to become members of the greatest of all the learned professions would no longer be densely ignorant of that profession's history and of the names of its great men.

I am constantly advising young engineers to join the various engineering societies, and to become personally acquainted with engineers of established reputation, and I can do no better than to repeat this advice for your benefit.

I counsel you also to read two or three of the principal engineering papers and magazines, so as to keep in touch with what is going on in the engineering world. After a while you should write occasionally for these periodicals.

Make it a matter of pride to keep all appointments promptly. An established reputation for so doing is a strong point in a man's favor, and tends to render him popular among business men whose "time is money."

During your technical course, visit and examine thoroughly as many engineering constructions, manufactories, etc., as your time will permit, and make notes thereon in your pocket-book for future reference. Study the why and the wherefore of everything you observe, and do not be content with half-understandings. Study also to see whether you can evolve ways of improving the various works, plants, methods, machinery, and mechanical contrivances that you encounter, for there is always the possibility of your discovering something of value; besides you are sure by so doing to develop greatly your mental faculties.

Learn to use your judgment and to decide quickly and finally. Some engineers make a point of having a string tied to each of their decisions, with the natural consequence that they fail to accomplish much and never finish a piece of work cleanly and thoroughly.

If possible, a design for any construction should be made complete at the outset before any actual work is done, as changes in plans involve trouble and expense for everybody concerned, and tend to produce patchwork.

Don't make up your minds that you will either like or dislike any particular branch of the profession before you have had considerable experience in actual practice; because, if you do, you are likely to make a mistake. Years ago I made up my mind that bridge engineering would not be to my taste, simply because I saw one of my fellow graduates with his head bowed over a drawing board, making a tracing. It seemed to me then that such work must be the *ne plus ultra* of uninteresting occupation; while to-day I am convinced that of all the numerous and diversified branches of civil engineering there is none to compare with bridge work in the absorbing interest that it involves for those who adopt it as a specialty. So much for early and immature impressions—beware of them, lest they lead you into error!

Some inexperienced young men think that an engineer should devote his entire time to strictly engineering work, and that any portion of it spent in any other occupation is wasted. This is another fallacy that ought to be exploded. It is true that there are some engineers whose entire time is confined to purely engineering work, but these men are computers and the like, who grind away from one year's end to another on intricate but tiresome calculations, and whose salaries never attain to munificence; while most of those engineers who spend a large portion or perhaps all of their time on business matters earn eventually large compensation.

One of the most important duties that an engineer is ever called upon to perform might be considered by some people as not being engineering at all. I refer to the work that he does in aiding projectors of enterprises to obtain financial support for their schemes. An incident or two from my own practice will serve to illustrate this kind of work and its importance.

Some ten or twelve years ago I was acting as consulting engineer to a promoter, who was trying to obtain money from some Eastern capitalists for a project involving a large bridge and a terminal railway system. At first the promoter's ideas were very large, and his project did not appeal strongly to the capitalists, so by degrees he lopped off one extravagance after another till at last he reduced the total sum required from over two million dollars to seven hundred and fifty thousand. This was a bed-rock figure, and he knew that if he failed to get the money this time the jig would be up; hence he took me East with him to interview the powers and to support him in his arguments.

By this time the financial men were getting tired of the project, so after giving my friend a hearing they excused themselves and retired for a consultation. In about half an hour they returned and reported that that would be the last time they would ever listen to the project, and that the decision they were about to announce would be final.

Then they stated that they would be willing to take five hundred thousand dollars' worth of the securities, if within three days my friend could place the remaining two hundred and fifty thousand dollars' worth. This decision seemed to take the promoter's breath away, for he recognized it as a "bluff" made to "freeze him out," and he did not dare to "call" it; so he kept absolutely silent for several minutes.

Seeing that my principal was placed *hors de combat,* I arose and said, "Very well, gentlemen, we shall be here on Thursday at noon with subscriptions for the two hundred and fifty thousand dollars;" then we took our departure.

When we got outside of the building my friend said, "What is the use in trying to work a bluff like that? You cannot possibly raise such a sum of money in three days. How do you expect to do it?"

To which I answered, "We can arrange the affair in forty-eight hours by giving a private contract for the superstructure to the ——— Bridge Company and another for the substructure to the ——— Foundation Company, on the condition that each concern will take in part payment one hundred thousand dollars' worth of the securities; your friend, Mr. So-and-So, will take twenty-five thousand more, and you and I together will put up the other twenty-five thousand."

All this was worked out as I planned, and on Thursday at noon we were at the office of the capitalists with all the subscriptions taken—much to their amazement, and, I may add, to their dissatisfaction.

Here is another example of financiering by the engineer after the promoters had failed. I sometimes tell the story by making the broad claim that I am the man who prevented the capital of Missouri from being removed from Jefferson City to Sedalia.

For a number of years I was working on the project to build a wagon bridge across the Missouri River at Jefferson City; but it failed to materialize for quite a while. At last the citizens of the city subscribed a sufficient sum to warrant the work being started, and I was retained to make surveys, prepare plans and specifications, and let the contract.

According to instructions, I made layouts and estimates for a high bridge at the foot of the central street of the city and for a low bridge some distance upstream, reporting in favor of the latter, not only because of its smaller initial cost, but also because the annual charges for maintenance would be much less. The committee, however, preferred the other bridge, consequently my recommendation was ignored and a contract was let for the high bridge, notwithstanding the fact that only a portion of the necessary money had been subscribed. The most strenuous efforts failed to raise the balance of the subscription; and one day I was called to Jefferson City to meet the committee, who, after consultation, informed me that the project would have to be dropped.

Shortly before this, there had been inaugurated by the people of Sedalia their big fight for the capital, one of their strongest pleas being that Jefferson City was difficult of access from the North during the winter, when the ice was not safe, and during the high-water period when navigation was dangerous, and that consequently legislators and others, in order to cross the river, often had to go all the way to St. Louis and back. The people of Jefferson City were feeling pretty blue just then, for they thought the capital would certainly be lost to them.

After hearing the decision of the committee, I replied, "Well, gentlemen, you would not take my advice and build a low bridge upstream, and now you see the result. You could have managed to raise enough money for a low bridge, while you cannot raise enough for a high one. My advice to you is to reconsider your decision, and revert to the low bridge project."

To this one of the committee replied, "You seem to forget that Senator Vest told us the Missouri River Commission would not permit us to build a low bridge over the river."

My answer was, "I have already built two low bridges over that river in spite of the opposition of the Missouri River Commission, and I see no reason why I cannot build a third. I suggest that you send a representative to Washington to interview Senator Vest and tell him that it has to be a low bridge or no bridge, and that the latter means the loss of the capital."

This was done, and a charter for a low bridge was soon afterward obtained from Congress; then I was called again to Jefferson City to advise what to do about letting another contract.

I told them they had gotten into hot water by acting against my advice in letting a contract not only for something which they did not need, but also before the money had been raised, but that I thought I could help them out. So it was arranged that they would get subscribed at once the small balance necessary for a low bridge, and that I would prepare plans, specifications and estimates therefor, and then effect a compromise with the contractor by making an agreement with him personally. Fortunately, he was reasonable in his demands, so I closed the matter and prepared a new contract, which was signed by both parties without delay, after which the construction of the bridge was pushed to completion.

When the vote on the removal of the capital to Sedalia was taken, the people of the State opposed the change, mainly because the principal plea for removal was no longer valid.

I have entered minutely into the details of these two cases, possibly too deeply for an address of this kind, but I wanted to convince you that there is often required from an engineer just as important work as engineering pure and simple. That it is impracticable to teach at a technical school how to handle financial problems and matters of that sort goes without saying, for such things can be learned only in active business life. Nevertheless, it would be a great step in this direction if engineering students were well grounded in political economy and the elements of finance.

Lectures on technical subjects at least once a month by practical engineers of high professional standing would bring the undergraduates into touch with the business world, and would enable them to see the practical application of many of their studies. Another way to effect the latter *desideratum* is to have the professors of engineering make a practice of spending a large portion of their vacations in the employ of consulting engineers and contracting companies, so that they themselves may learn how to apply theory to practice, and teach the same afterwards to their students. Several professors of engineering have thus entered my employ, and all have expressed themselves as well content with the practical knowledge they have so acquired.

If engineering students were instructed properly in the practical application of all the theory they learn, they would undertake their studies with more enthusiasm. However, it requires a practical engineer to give practical instruction; hence the suggestion just made concerning vacation work for the professors.

It may be difficult to show the practical application of some of the courses of the curriculum, especially the pure mathematics, still it can and ought to be shown.

Learn to distinguish between the use and abuse of approximations. Some calculations should be made with extreme accuracy, while others need be only approximate. Engineers are apt to err in either direction. For instance, it is a difficult matter to teach an experienced railroad engineer that, when making a large triangulation for a proposed bridge, it is necessary to measure his base lines to a hundredth of an inch and his angles to a second; and, on the other hand, many bridge computers have wasted months—aye, years—of their lives in struggling with that useless method of figuring stresses by wheel concentrations. Your maturing judgment will soon tell you how close to exactness any set of calculations ought to be made in order to obtain correct results. Any greater accuracy amounts to mere hair-splitting.

This last phrase reminds me of an amusing incident in my career. I was once called upon to pass on some plans for a bridge which were submitted to a city by the successful bidder. Among other faults, I pointed out that the hip and pedestal pins were located on the center line of the channels of the inclined end post instead of on the gravity line of the sections of the member. The foreign engineer who had prepared the plans wrote to me in their defense, and stated in reply to this particular criticism that my objection was nothing but the "splitting of a hair." I thereupon sent him a copy of my calculations, showing that the little eccentricity, which he wanted to ignore, increased the maximum stress on the extreme fibre fifty-nine (59) per cent. This letter brought the correspondence abruptly to a close.

It is far better for a student to make all his calculations in scratch books rather than on loose sheets of paper, for he will then be able to refer to them at any time and check them if necessary. You can begin right here applying the principle of systemization of work by keeping your calculations neatly and in such order that reference to them may be easy.

There is one important matter which is neglected in most engineering schools, viz., the use and adjustment of all instruments employed on engineering work. Of course, the use and adjustment of transit and level are taught more or less thoroughly at all technical institutions; but how many of their recent graduates can take one of these instruments apart, clean it, effect simple repairs, and put it together again? All these manipulations are necessary occasionally in field work, where the party is hundreds, perhaps thousands, of miles from the nearest repair shop.

Again, there are in use nowadays by engineers several improved attachments to the transit and level; and these two are by no means the only instruments which engineers employ.

Take my advice and learn all you can concerning engineering instruments before you leave your *alma mater;* for you may not have another opportunity to do so before you are required to apply the knowledge that I am advising you to acquire. Moreover, you are liable to forget in time a great deal of what you learn here about instruments. In proof of this let me give you a little illustration from my own experience:

Last summer the Chief Engineer of the Province of British Columbia, who, by the way, is a very old friend of mine, and I found ourselves some five hundred miles up the Fraser River, about the fifty-second parallel, provided with a borrowed transit and level but no one to run them, and having before us the task of locating a suspension bridge across the river and the two approaches. There was nothing for us to do but to get down to first principles and operate the instruments ourselves; but as they had traveled some two hundred miles by train and nearly as much more by stage, it was first necessary to see that they were in adjustment.

"How long is it since you ran an instrument?" asked my friend.

To which I replied, "Over twenty years."

"Well," said he, "I have not touched one for twenty-five. Do you know anything about making the adjustments?"

"Yes, at least I ought to," I answered, "for I gave the course in adjustment of instruments at Troy, but probably I have forgotten all about it."

We first tackled the transit and found that we could remember the three adjustments pretty well; hence tested for them and soon got that instrument into good condition. Next we attached the level, which we found to be a dumpy.

We set it up and looked at it a few minutes without speaking. At length my friend remarked:

"Confound a dumpy level, anyway; I never could handle decently one of the infernal things. How in Hades are we going to get it adjusted?"

I replied, "If I remember rightly, we shall have to use the peg method, but it is over twenty-five years since I handled one of the accursed instruments, and I have forgotten nearly all I ever knew about the adjustment."

To make a long story short, we two old engineers struggled with that miserable instrument for three-quarters of an hour before we got it into sufficiently good adjustment to answer our purpose, after which we proceeded with the surveys, finding by degrees our old skill coming back to us to such an extent that, on the third day, when we had finished our work, we agreed that we had enjoyed it thoroughly, notwithstanding the fact that we had slept for two nights in the rain without any shelter but our blankets and a small piece of canvas.

Let me advise that, both as students and engineers, you cultivate a love for your occupation. Unless you do, you will never attain great success. The longer you are engaged in engineering the more interesting and absorbing does it become, and eventually you will begrudge from your work the hours spent away from it even in sleep. There is no satisfaction that I ever experienced which quite equals that resulting from the complete solution of a difficult problem in either theory or actual construction.

The maintenance of a high standard for the engineering profession is the duty of every engineer both to the profession and to himself. The strictest integrity under all circumstances is absolutely essential to an engineer's success. Any departure from it is sure to bring disaster to the individual and disgrace to the profession; therefore let me exhort each of you always to do the right thing to the best of your knowledge and power.

At all times you should endeavor to maintain the dignity of your profession, remembering that the public is not likely to place that profession upon a higher plane in the affairs of men than do its own members; therefore never speak of it in a belittling tone; but, like a knight of old in respect to his lady's fame, be ever ready to maintain its superiority against all comers.

And now a few words in regard to the requisites for a man's becoming a successful engineer.

He must be intensely practical, yet perfectly technical; minutely accurate, yet properly approximate; firm in his beliefs, yet open to conviction, knowing where firmness stops and stubbornness begins; courteous and helpful to his contractors, yet never conniving with them to the slightest degree; dignified, yet affable; and, in short, a thorough gentleman, yet never ashamed to do any work, however apparently menial, provided that it belongs properly to the engineering profession.

In order to encourage you young men to renewed effort, let me state that I most firmly believe civil engineering to be less overcrowded than any other profession; that the demand for good engineers is increasing steadily; that the problems confronting engineers are yearly becoming more complicated, demanding a higher grade of talent and training; that the remuneration for engineers of all ranks in this country is higher than ever before, and that the prospects for the future of our profession are exceedingly bright.

In corroboration of the preceding statement I quote the following, which I read (after this address was written) in the Engineering Record of March 28th:

"The demand for engineers throughout America far exceeds the number of men available. Several engineering colleges report already that more good places are offered than there are students in the graduating classes to fill them, and this in spite of large classes and improved facilities. Several prominent technical institutions are adding new buildings and increasing their equipment."

Before closing, let me offer you, as a summary of most of my remarks, a few concluding words of advice in regard to the remainder of your course at the Missouri State University, which, if you follow, will give you an excellent preparation for the life work that is to come after graduation. In all you do be earnest, honest, energetic, thorough, and ambitious. In short, strive to be worthy of having ultimately engraved on your tombstone that most expressive Colorado epitaph:

"He done his level damndest,
No angel could do no more."

COMMENT.

The student rarely has much, if any control over the curriculum. He finds both the course and the requirements for matriculation laid down completely, though a few institutions are now offering optionals in the Junior and Senior years. In general, he may be better prepared than is essential, and he may do better and more thorough work than will enable him to obtain credit for his subjects, but he is unable to modify his course except in the few cases in which he is permitted to pursue additional studies. Consequently, remarks upon the subjects which constitute the course are more properly addressed to the faculty than to the students. But, by his own election the student may determine what shall be his preparation, how vigorously and earnestly he may perform his undergraduate work, how much more he will do than is actually necessary, and how he may broaden and strengthen himself by collateral reading and by work during his vacations. The resulting education is probably dependent quite as much, if not more, upon these considerations than upon the prescribed course, the institution's equipment, and the efforts of the faculty.

The age at which a student shall enter upon his engineering studies is largely dependent upon the extent of his preparation. An Arts course, in which electives are chosen with reference to the engineering work, is by all means the most satisfactory equipment with which to begin the technical studies, for it will provide culture, breadth of view, and studious habits and will occupy the student till his nineteenth or twentieth year. With this age and training he will possess the practical judgment which is essential to good work in the engineering courses. The very young student does not, as a rule, grasp the true meaning of his studies, hence is unable to make a good fight for position and advancement after graduation.

The more advanced age commonly brings with it a sense of responsibility and establishes the young man's purpose. He realizes that he should do thorough work for his own benefit rather than for passing grades. He takes small interest in deluding the professors with a false show of knowledge and is able to enter into more cordial relations with them. He grasps his subjects more quickly and thoroughly and comes out of school with advantages which more than compensate for the loss of time in practice.

The relations between professor and student are undoubtedly much closer than they were not many years since, for the teacher's calling, like the clergyman's, has lost some of the undue importance which was formerly attached to it, and he does not consider it beneath his dignity to be the student's intimate friend. Confidence and cordiality beget confidence and cordiality, and both student and instructor will profit by the effort to enter into closer relations, but the student should make the greater effort, for his is the greater gain. There are, however, too many instructors who are deficient as men; that branch of the profession has no monopoly of the capable and broad-minded engineers, in fact, there are a good many lazy men who enter it because it promises an easy life. These should be ruthlessly weeded out, for as teachers they are in position to do great harm to the rising generation.

There are always a few students who mistake their calling, who have not the ability in scientific lines to make a reasonable success of engineering. The slow man is not necessarily stupid. In fact. he is often exceedingly sound. But the one who is obviously on the wrong track should be so advised. Otherwise. he will spend money, labor, and time, and reap only discouragement and disappointment. The training might fit such men for business, but more often they stick to engineering and struggle through life miserably. The kindness which keeps back the truth in such cases is almost criminally misplaced.

The slow student needs help, encouragement, and often pressure. The "smart" man should be reasoned with, should be shown that he is wasting his energy, and if reason does not avail, he should be brought to his senses by more forcible means. His control is essential to the welfare of his fellows.

The student should do all his work with equal fidelity and thoroughness. His taste may lead him to give some studies especial attention and to neglect others, a procedure which he is sure to rue sooner or later, for his opportunities may require a knowledge of the very subjects he has slighted. A sound knowledge of the fundamental principles of all his courses should be his goal, leaving specialization to practice. It is easy to specialize, but it is difficult to be broad.

The student is commonly impatient under the attempt to drill him in clerical methods, considering them non-essentials and time-wasters. Systematic and thorough attention to detail is often foreign to the life habits of the young man who has always pursued his own way. In his opinion the idea is the thing, the method nothing; the work interesting but recording it drudgery. No greater mistake could be made, for orderly habits will enable him to increase his capacity for work, save time and temper. establish his knowledge more firmly in his mind, and, ultimately, make or mar his career. All careless and unsystematic habits must be unlearned and replaced by good ones before advancement is possible in practice. It is exceedingly discouraging to find a young engineer unable to record his calculations so that they may be checked; indeed, it frequently occurs that he cannot retrace them himself. Nothing is "good enough" unless it is the best the work warrants or the best one can do.

Habits of promptness and regularity are also of the greatest value, for they are absolutely essential in business. The young man, particularly, cannot afford to fall into lax habits. He should be just as prompt and regular in his attendance on his classes as he must be in his later employment. To attend the classes of a lazy or dull instructor is severe punishment but good preparation for the drudgery that will sometimes be met with later. The habit of coming onto the work or into the office late is very common among young engineers, but it always works to their detriment, for it is rightly considered an evidence of laziness and lack of interest in the work. The chronic time server is frequently late and always ready with an excuse which is generally manufactured for the occasion. This lazy habit is very commonly acquired in school where the professor has not the ready and drastic remedy for it that the employer possesses. The lazy men make it necessary for large establishments to keep a check upon the assistant engineers and draftsmen, just as they do upon the laborers and mechanics.

The editor does not agree with Dr. Waddell that the foreign languages are of little or no use. The smattering of them too commonly given to engineering students is so, but with a knowledge of the grammar and the ability to read at all, any ambitious student can readily acquire a good working knowledge of French and German or both by reading the technical periodicals in those languages, thns increasing his knowledge of the languages and of engineering at the same time. Excellent descriptions of American machinery and constructions often appear in the French and German papers long before they do in our own, and the foreigners are generally much more thorough in their discussion of the theory involved. Spanish is rapidly growing to have a commercial value and merits thorough study. It is without important technical literature, however.

The Latin certainly has no place in the technical school, but familiarity with it greatly aids the English. The study of etymology will afford some knowledge of roots, but the Latin will do so much more thoroughly and pleasantly. Without a good, working knowledge of the derivation of English words, nice distinctions and clear expression are impossible.

The grammar and rhetoric of the English language are rarely or never clearly understood until one has studied Latin or Greek or some of the modern languages, for the essential character of their laws is difficult to comprehend, since a working knowledge of the language has been acquired without acquaintance with them. Studying the construction of another language brings home the construction of one's own as nothing else will.

It is true that there is more written in English than the busy man can find time to read, but much of it could advantageously be passed over in favor of the best in French and German. The greatest works in these languages are translated into English sooner or later, but it is a disadvantage to be without them in the interval.

Again, American firms are rapidly establishing branch offices in foreign countries and, in order to fill them, need engineers who are thoroughly familiar with American methods and who understand the language of the country to which they are sent. These positions often afford excellent opportunity for advancement.

The student's knowledge of English cannot be too thorough. Much reading of the English classics will unconsciously exert a great influence over one's use of the language and will afford culture and breadth at the same time. It will not take the place, however, of thorough drill in the laws of construction and in criticism. Continuous work in composition, with careful criticism and thorough instruction, is essential if one is to acquire a good knowledge of his own language.

The vast amount of reading essential to acquaintance with the superabundant literature of the present day leaves little time for the writing and the verbal discussion which give facility in the expression of ideas. In fact, there is a strong tendency to read and absorb rather than to think and write, hence the student should grasp every opportunity to give expression to his opinions when so doing will be helpful.

The work in mathematics should be performed with painstaking thoroughness, for however readily the idea may be grasped it will be evanescent unless it be turned over in the mind and applied. Accuracy and completeness afford much pleasure, too.

The ability to see in one's imagination the construction or movement of a member is essential to rapid and true work in designing, and no other study is so valuable in the development of this faculty as descriptive geometry. Even if this were its only value, it would handsomely repay careful attention, but it is of great assistance in projection drawing, and its use will save much tedious calculation in detailing.

Every engineering student should be a thorough draftsman before graduation day arrives. He should be able to make a good, neat, and complete tracing with reasonable speed. The lettering should be neat and plain. There is no time for fancy lettering in practice, but poor lettering ruins an otherwise satisfactory drawing. The majority of engineers begin their work in the drafting room; consequently advancement is largely a matter of skill in drawing. The competent draftsman will soon obtain the opportunity to oversee the work of others, the first step toward an executive position, for one cannot direct work which he does not fully understand. Freehand skill is something of a gift, but it should be cultivated by all, because it affords the most ready means for the clear development and expression of ideas of construction.

Nowadays, one-third of the summer vacation is spent upon field work which has recuperative as well as educational value. Another third, at least, might be spent advantageously on some engineering work or in some shop. Experience rather than money should be the end sought, hence, if the student's finances will permit, he should offer to work without pay in order that he may be the more free to demand instructive labor. The ability to make a good drawing will practically insure summer employment. If he go into the shops or out upon construction, he should remember that no well performed service is undignified and that long hours and hard work are to be accepted cheerfully and with alacrity, even though his name is not on the pay rolls. His own habits and character are in the making and he cannot guard them too carefully. Besides, he is probably under the observation of those who will be in position to influence his future work, directly or indirectly, and it behooves him to do his best.

When information is wanted it should be sought freely. The honest and earnest inquirer will rarely meet rebuffs, and it is no crime to be ignorant, though it certainly is to remain so. The laborer, the artisan, the foreman, the engineer, anyone, is ready and willing to give information if it be sought in the right spirit. Foolish and ill-considered questions, however, soon bring such courtesy to an end. For instance, a prominent young engineer delivered a lecture to the students of one of our larger schools on the construction of deep foundations by the pneumatic process. At the conclusion of his lecture the professor advised the boys to question the lecturer upon any points which were not clear, whereupon one student inquired how the caisson is removed when bed rock is reached.

The student should cultivate an unprejudiced habit of mind, for the position of the engineer is in a large measure judicial. He stands between the buyer and the seller and, though he is generally employed by the former, he must be fair with the latter. He should be firm in his decisions, but willing to acknowledge error frankly when it is clear that error has been committed. The evidence should, however, be weighed as fully and carefully as the time available will permit. It is best to make up the mind slowly, obtaining all the information possible, but delay is damaging when decision is actually necessary.

Honesty is still the best policy. To cheat an instructor prepares the mind for grosser crimes. The descent from strict rectitude to rank dishonesty is gradual and easy, and ground lost is exceedingly difficult to recover. The young and ambitious engineer is frequently tempted, not often openly or grossly, but insinuatingly, with flattery and favor rather than with money. A contractor's or a salesman's bribe, no matter what its form or how insignificant, is monstrous, for its acceptance marks the beginning of a dishonorable end. It it be accepted secretly, the secret will be kept only so long as it serves the giver's purpose to keep it, and sooner or later the matter is published abroad. No compensation is adequate for the loss of an engineer's honesty, and it is no less dishonorable to give bribes than to receive them. It is a matter for congratulation and pride, however, that the black sheep are rare in the ranks of the civil engineering profession. Strict honor is the rule, rather than the exception, and it lies with the present generation of students whether this condition shall continue to obtain.

It is to be regretted, however, that envy may with justice be more commonly charged. The strife for position is great and occasionally leads to unfair, unjust, and dishonorable action, which generally rebounds upon the guilty party, not without damage, however, to his opponent. Of all faults those arising from envy of another's prestige or good fortune are the least excusable and the least in keeping with the dignified and honorable character of the profession of civil engineering.

SPECIFICATIONS.

A LECTURE DELIVERED TO THE

SENIOR CLASS

OF THE

RENSSELAER POLYTECHNIC INSTITUTE

ON APRIL 30, 1903,

BY

J. A. L. WADDELL.

INTRODUCTORY NOTES.

Specifications prescribe the limits of the construction they govern and the qualities of materials and workmanship which enter into it, and they define the relations which shall exist between the parties to the contract, of which they form a part, and the degree of responsibility which attaches to each. If complete plans have been prepared and all the conditions which affect the construction were known and fully considered in advance, the specifications should constitute a full and complete description of the construction, the materials and workmanship employed, the relations between the parties, the responsibility for accidents and for the durability of the completed structure, the terms of payment, and all other matters which affect the work.

Specifications are drawn in the interest of the payer, and they should contain ample safeguards to insure the construction of the work in accord with their letter and spirit, but they should be fair, eminently so, or they will fail in their full purpose. Unless a contractor knows the engineer and his principals to be fair beyond dispute in their dealings, he must add materially to what would be a normal tender for the work, in order to insure himself against serious loss whenever unfair specifications govern. Even a close personal acquaintance and previous experience with the payer and his representatives are insufficient guarantee that an unfair specification will not be enforced, because a change of principals or agents may, often does, take place during the execution of the contract; and a wise contractor will not run the risk of rigid enforcement of the specifications without corresponding compensation. Consequently, every unfair advantage is paid for in the price of the construction, though it is of little or no value to the payer.

Unfair clauses in specifications almost invariably operate to the detriment of the party in whose interest they were drawn, by producing a hostile and revengeful spirit on the part of the contractor, leading him to avail himself of every opportunity to demand extra compensation and extra time allowance for small considerations which are ordinarily overlooked where cordial relations exist.

The payer may retain full control over the work and safeguard himself against bad materials and workmanship, against unreasonable delays, and against a contractor's dishonesty without the slightest injustice to the honest contractor, and if such action cause dishonest contractors to refrain from bidding, it is all the more advantageous.

The editor has prepared several tenders upon work for each of two of the most prominent railroad systems in this country. The contract and specifications of one company are stringent but just; those of the other bristle with clauses which a responsible contractor cannot accept without jeopardizing his interests. The former obtains the best work at fair or low prices and with a minimum of trouble. The latter receives very high tenders or none at all from the most responsible contractors, gets an inferior grade of construction at high prices, and is constantly having difficulties with the contractors. The difference between the results these companies obtain is very great, and their specifications and contracts are responsible for it.

The importance of the specifications, especially of their broad general clauses, is too rarely understood. If the engineer who draws them could exchange places for a time with the contractor, he would soon learn that over-stringent clauses operate to his detriment and, what is even more important, how it is possible to take advantage of his failure to specify definitely what he requires. As a rule, it is the broad general clauses that are most important, for they affect the entire work, while the clauses pertaining to details govern a small portion only. Ambiguous clauses are the most detrimental of all. They insure high tenders, for in justice to himself the contractor must assume that the interpretation most contrary to his interests will obtain. They provide the foundation for quarrels, law-suits, and vexatious and expensive delays.

Good specifications are the result of long and sound experience in construction and in the preparation of plans and specifications. If a part of the experience is obtained in the employ of contractors, the results are more likely to be satisfactory. The engineer's knowledge of what constitutes good construction and how to obtain it, is the accumulation of years. The foundation for his knowledge, and the foundation only, may be laid during his course of study in a technical school. The weaknesses and effectiveness of the various clauses may be learned only by repeated use, and it is work well spent to review the specifications and contract after the completion of the work they governed, and note the desirable improvements and the fitness of individual clauses for future use. Thus the results of the experience on one contract may be made available for the next, but indiscriminate copying from the specifications of others, or even from one's own, is certain to produce bad results. Not long since one of the engineering journals called attention to an absurd typographical error in a set of specifications which had been in print for several years, and pointed out the same error in the specifications of several prominent engineers, showing, conclusively, that some careless copying had been done.

It is impossible for our technical schools to teach men to prepare perfect specifications, but they can provide a good foundation by imparting a sound knowledge of the fundamental principles and such a thorough training in the use of the English language that the student will be able to express clearly what is in his own mind. Professional work, a further study of the law of contracts, and careful attention to the specifications prepared by competent engineers, must supply the additional necessary training. Lectures, such as the following one which Dr. Waddell delivered to the students of the Rensselaer Polytechnic Institute last year, are exceedingly helpful to the student and to the recent graduate. A good set of specifications form an excellent text and merit careful study. A close examination of the various clauses to determine the relation each bears to the whole, the considerations which led to their adoption, and the particular purpose for which they are inserted, is eminently worth while.

SPECIFICATIONS.

A Lecture Delivered to the Senior Class of the Rensselaer Polytechnic Institute on April 30, 1903.

By J. A. L. Waddell.

Thus far, in addressing you, young gentlemen, I flatter myself that I have interested you and held your attention fairly well; but now I am going to risk ruining the prestige that I think I have gained among you by giving you a long, tedious talk on the dryest of all dry, technical subjects—specifications.

Dry, however, as the subject may be, there is no other of greater importance in engineering practice; so I feel that I would not be doing either my duty by you or justice to myself were I to spare you the infliction of this last lecture, merely for the sake of trying to leave on your minds the impression that I am an interesting speaker. It will therefore be necessary for you to take your medicine philosophically, and I am going to ask you to give me your closest attention and to endeavor to interest yourselves in all that I say, notwithstanding its extreme dryness.

The substance of this discourse was blocked out a month ago by Mr. Ash, one of the assistant engineers of my firm, and by myself working jointly; it was then partly written and delivered by him to the engineering students of the Missouri State University. Since then I have revised and enlarged the lecture considerably for your special benefit.

Between the individual or corporation desiring the work done and the contractor who performs it, stands the engineer who has designed it and who usually superintends its execution. He is in the employ of the persons promoting the enterprise, and it devolves upon him to make sure that those who retain him receive an honest and fair return for their money. While it is true that he is employed by only one of the parties to the contract, he should not be partisan, but should strive to see that fairness to both is secured. The engineer should not be an enemy to the contractor, but should work in harmony with him, and should do all he can to further the rapid and harmonious completion of the work, being careful, of course, to see that nothing is done which will in any way result in an inferior construction. As the engineer's decisions are final (unless it can be shown that actual fraud exists) it behooves him to be careful that no injustice is done to anyone.

In order that the contractor may understand the scope of the work to be performed and the details of its construction, a written description and plans more or less complete, defining the methods of construction, material, etc., to be used, are prepared by the engineer for the approval of the company having the work done and for the guidance of the contractor. These written documents are the specifications, and together with the contract, of which they form a part, they fix definitely the relations that shall subsist between the company or corporation and the contractor.

To build a structure, no matter how simple, there must be a plan, if it is to be constructed intelligently and efficiently. As the size and importance of the structure increase, the plan grows more and more complex, and hence the greater necessity for putting it in some fixed and definite form which shall convey the exact idea existing in the mind of the engineer. To secure the proper execution of a work of any magnitude, specifications are absolutely necessary, and they should be prepared with great care and exactness. For convenience of reference and for clearness, they are usually divided into clauses, which may be classed as general and specific. General clauses refer to the business relations that shall exist between the parties to the contract. In them is found the general description of the work as a whole without any particular reference to details. Times and methods of making payments, adherence to specifications, inspection and other analogous headings make up their subject matter. They should be comprehensive in their scope, and should not contradict one another. It is well to avoid a double description of any particular thing. Contradictory clauses are sure to be a stumbling block that will create friction and delay. At first glance one would say that such clauses are easily eliminated, but care is necessary to accomplish this. For instance, a certain result may be desired in the substructure of a bridge that will not fit in with the kind of superstructure wanted.

Specific clauses have to do with the details of construction and the description of particular features of design. They embody the special ideas that the engineer wishes to incorporate in the work, and they should be just as minute in detail as is requisite to set forth the exact plan desired. Detailed drawings may be necessary to indicate clearly just what is to be done, and these drawings either should be prepared before the specifications are written, or at least should be sufficiently matured in the mind of the engineer to enable him to write his specifications in accordance with them. It must be remembered that the specifications and plans constitute a guide book for the contractor and the resident engineer. They should tell what must be done, but should not necessarily state just how it should be done. Specifications should look to the accomplishment of an end rather than to the means of its attainment. Of course there are exceptions to this, as when the engineer believes that for the best results work must be performed in some particular way, in which case it is necessary to incorporate the method in the specifications. It must be remembered that under these circumstances the contractor cannot be held responsible for the mistakes of the engineer. When an engineer specifies that a thing shall be done in a certain way, he must assume the responsibility of the outcome, because the contractor is not free to adopt the method he thinks best suited to the case in hand. For this reason specifications should leave the method, as far as can be done consistently, to the contractor, and instead should dwell upon the end to be attained. A good contractor who is active and progressive may frequently wish to introduce methods of construction better than those conceived by the engineer, and it were a poor set of specifications which would prevent his doing so. A specification can readily be very strict concerning the finished work and at the same time very liberal as to the methods to be employed in its accomplishment.

It frequently happens that specifications are written without any accompanying plans at all. In such cases it is usual to require bidders to submit with their tenders plans more or less detailed of what they propose to do. In this way the engineer may make a choice from various plans presented and thus obtain what he considers the best of a number of ideas. Specifications of this kind will have, of course, very little or nothing at all to do with the details involved, but will be concerned almost entirely with the final desired outcome. In other words, such a specification will consist very largely of general clauses, those of a specific nature being either entirely eliminated or reduced to a minimum. This method of letting contracts without any accompanying plans is by no means to be commended. A good engineer does not want other people to tell him what to use or what to do. If he is thorough and well posted in his profession, he is not going to let his own ideas be superseded by those of a contractor who furnishes plans with his bid. In such a case the engineer becomes only an inspector who simply passes upon the work and determines whether or not it fulfils requirements, when perhaps much of the work is entirely at variance with his own ideas. It is reasonable to suppose that an engineer who devotes his entire time to designing structures of a particular kind (and no one man will attempt to cover the entire field), is more capable of arriving at the best design for a given case than a contractor who is engaged in work of a varied nature, and who perhaps has given little or no thought to the designing of the particular kind of structure upon which he desires to tender. It is undoubtedly a fact that the best results are accomplished when the plans and specifications are prepared by a competent engineer, and when the bidder is governed by their requirements.

Let us consider some of the salient features of good specifications. Primarily, they should give a clear and concise description of the work, first when considered as a whole, and then in detail, no part being slighted in this description. It will not answer for the engineer to suppose that the contractor will do things as a matter of course, but he must produce a specification that will *insure* their being done. A contractor, if he be thoughtful and careful, will pay close attention to every detail set forth in the specifications, and he should make his bid expecting to fulfill just the requirements enumerated in them, no more and no less. If he be wise, he will not bid with the expectation of having them changed to conform to his convenience or his notions of what is best. The engineer is supposed to have stated in his specifications just what he wants, and no prudent contractor will tender, expecting his own ideas to prevail. If, then, upon the engineer devolves the responsibility of determining the work to be done, it will readily be seen that it behooves him to cover the entire ground in his specifications. He should give special attention to the points he intends to require absolutely without alteration and should leave no possibility for doubt in the mind of the contractor as to what will be expected concerning them. He should be careful to set forth clearly the units of measure to be employed and what is to be considered a part of the finished work, as distinguished from what is merely accessory. If extra work is to be performed, the amount of which it is impossible to determine in advance, the greatest care should be exercised in defining clearly just what shall constitute such extra work and in fixing the compensation for it. Failure to do this is frequently a source of trouble and annoyance that might be avoided by careful wording.

Specifications should be designed to secure the best results consistent with what is considered good practice. It is possible to make requirements of such a nature that to fulfill them would mean an enormous outlay of money not at all proportionate to the result. Such clauses in a specification make a bidder uneasy and will cause him to add to his bid a sufficient amount in addition to his profit to insure him against loss. A bidder should make his tender expecting to comply with the conditions of the specifications, and expecting that his fellow bidders will do the same, and a clause that involves an unduly strict condition is liable to cause him either to tender high or to bid hoping that its fulfilment to the letter will not be demanded. In nine cases out of ten such a clause will be dearly paid for.

Absolute perfection is not to be expected, but the very best that the most approved practice will afford should govern the requirements. An engineer must lose prestige if he specify things which cannot consistently be done, and by inserting such requirements he works injury to all parties concerned. In the matter of materials to be used he must be governed by the locality and by what the market has to offer. He may be unable to get just what he would like; therefore he must use the best that can be obtained. These remarks do not imply that the engineer should be satisfied with any makeshift that is offered. He can rest assured that he will not receive anything *better* than he demands, and he is fortunate if he succeed in getting everything as good as he specifies. As he is a large factor in determining what shall be considered good practice, he should not be content to put up with shoddy stuff when better can be obtained. As in all business relations, moderation with firmness should govern.

Again, specifications should be written in simple, plain language without any attempt at rhetoric. All verbs should be complete, and no words should be omitted on the assumption that they are understood. Of course, the law will interpret a contract or a specification in accordance with what the court decides is its spirit, but an engineer should not rely upon this to guard against omission. If the specifications are properly prepared, there should be no occasion for appealing to the courts to decide what is or is not the spirit intended. While such documents should be comprehensive, they should not be verbose, and above all things they must not be ambiguous. Short sentences and simple words are preferred. Punctuation and grammar, while usually and erroneously considered of minor importance in an engineer's practice, certainly play an important part in this particular kind of literature. The meaning of a sentence can easily be distorted or even entirely changed by the placing of a comma. Do not fear to repeat the same words or phrases over and over again in your specifications, if you find they best convey the idea you have in mind. This may involve occasionally some lack of euphony, but that can very readily be dispensed with in writings of such a prosaic nature.

Should more than one contractor be employed upon a piece of work, great care must be exercised to define clearly the duties of each. Just where one is to finish and the other is to begin should be set forth so as to leave no possibility of doubt. When practicable in such cases, separate and distinct specifications for the different parts of the work should be prepared. Care should be taken that the same thing is not required of both contractors, and that one contractor is to leave his part of the work in such shape as to involve no hardship or inconvenience for the one who is to follow. As an illustration of cases of this kind, in bridge work it frequently happens that one contractor will do the substructure work while another will build the superstructure. It is then necessary to specify who is to set the anchor bolts and anchorages.

The engineer must be careful about putting anything into his specifications that has even the appearance of favoritism. He must be constantly on his guard to avoid this, for his position is such that his reputation is liable to suffer if he deviate in the least from strict fairness to all. It is bad policy, generally speaking, to require a particular brand of material or the product of a given firm without stating that other material will be accepted, if, upon testing, it be found of equal quality. When a given brand is well known and has an established reputation, it is sometimes proper to specify that it shall be used to the exclusion of other makes, but usually it is best to set a standard which is commensurate with the best product to be had, and then accept any brand which meets the requirements. An exception to this rule is permissible when specifying paint for metal-work, because, unless the particular brand be stated, the contractor is liable to give endless trouble by offering for test inferior brands, and the result is very likely to be the adoption of a paint that is not really satisfactory. Unscrupulous parties are ever ready to give the engineer a bonus in case he use their product, and that engineer is fortunate who has an extensive practice and is yet entirely free from all charges of peccability. Where one man's product is rejected and another's used, there is a great temptation on the part of the disappointed person to question the fairness of the proceeding. An engineer once guilty of crookedness is badly handicapped, and justly so, for no man wishes to entrust the expenditure of his capital to one who is not absolutely above suspicion.

To insure all the conditions that have been enumerated, it is evident that the engineer must familiarize himself with every detail of the work in hand. If he does not understand it himself, it is certain that he will not succeed in getting a clear idea of what he wants into the mind of another. Even when the scheme is perfected in the engineer's mind, it is difficult sometimes to make it plain to the contractor.

It will not do to jump at hasty conclusions, for very often one finds that an idea, which at first seemed to be just what was wanted, proves utterly untenable when considered in connection with other ideas that must be incorporated in order to produce a finished construction. No idea for a specification has any value until it has been fitted into the proposed structure, and is found to harmonize with all the other requirements.

It is usual and proper in specifications to insert a clause allowing the engineer the privilege of changing them or the plans as the work progresses, but it is desirable for all concerned that the number of these changes be reduced to a minimum. A perfect set of specifications would render such a clause useless; but since we have not yet attained to perfection, we must have some means of recourse, bearing in mind, however, that the more such a clause as the one referred to is brought into use, the farther we are from the ideal.

The question of precision is one which should never be lost from sight. If the engineer is to maintain his prestige, he must be precise. It will not do for him to say "about this" or "about that," for the "about" is very liable to assume proportions which were never dreamed of when the term was used. Of course there are times when it is neither necessary nor desirable to be absolutely exact in requirements, but generally speaking the word "about" has very little place in a set of specifications. What is put into them is placed there with the idea that it is to be operative and binding in the construction of the work, and it is the duty of the engineer first of all to impose no impossible or unwise conditions, and next to see that what he has required is fulfilled to the letter.

The specifications form a part of the contract, and when the latter is signed, the contractor agrees to all the conditions they set forth. It is proper to assume that he has read the specifications and is familiar with their requirements, and that he signs the contract and makes his bond with the full knowledge of what is before him. A specification should never hide from the contractor difficulties that are likely to be encountered. On the contrary, when such difficulties are known to the engineer, they should be specially called to the contractor's notice, so that he may bid more intelligently. His attention, however, should not be drawn to them in such a way as to frighten him and to cause him to make a bid abnormally high, but the facts as they exist and are known to the engineer should be stated. As in all relations in life, straightforward, fair-and-square dealing is by far the best policy. No railroad company or other corporation is benefited by letting a contract for a sum below the actual cost plus a reasonable percentage for profit, since the delays incident to the contractor's failure, and the litigation that is likely to arise will more than counterbalance the supposed saving. No contractor who is losing money is going to make the same exertion to accomplish his task properly as one who realizes that he is earning a fair profit.

In spite of every precaution that may be taken, it is almost impossible to avoid mistakes entirely. A given proposition may appear to the engineer in his office before work has commenced very different from what he finds it in the field after the construction has begun. When an engineer discovers that he has made a mistake, he should not hesitate to acknowledge it, and to set about, as best he may, to correct the error. He should lose no opportunity to check against errors and should be thankful when they are discovered in time to prevent harm. To reduce mistakes to a minimum the engineer must be thoroughly conversant with all contingencies likely to arise in the execution of the work. He should familiarize himself with the appliances ordinarily employed, and should so design his work that their use is not prohibited. In writing his specifications and in making the plans, he should have a clear and complete mental picture of just what he is striving to attain. It must be remembered that if the specifications are lived up to, they will entirely determine the result, and that it is the plans and specifications wherein the creative power of the engineer asserts itself.

Finally, when all is said and done, common sense must govern the interpretation and execution of any set of specifications. All should have but one object in view, the production of a structure that will be a credit to everyone concerned.

Up to this point I have been dealing mainly with generalities, but now

I shall go more into detail, taking up first general clauses and later specific ones. These general clauses will be ample for all engineering specifications, and can therefore be used for all kinds of engineering construction; but it would be impossible to cover the entire ground of specific clauses, consequently I shall simply quote some characteristic ones from specifications for different kinds of construction, and point out some of their peculiar features and *raison d'être.* Naturally, in offering you examples of specifications, I shall utilize some of those prepared by my firm, and shall trust that you will pardon me for so doing, because I am responsible for them, while of course I could not be accountable for the correctness of everything in case I were to quote from the specifications of other engineers. In order to present to you a wide range of specific clauses, I shall make extracts from specifications for bridge superstructures, bridge substructures, steel lighthouses, an ocean pier, and a steel pipe-line. From a study of these you will be aided materially in the preparation of specific clauses for any class of construction on which you may be engaged.

But first, in order to give you an idea of the ground which a thorough set of specifications must cover, let me read to you the alphabetical list of headings in our "Specifications for the Rebuilding of Ten Bridges on the International and Great Northern Railroad:"

Accompanying Drawings; Adherence to Specifications; Alteration of Plans; Anchor Bolts; Annealing; Approximate Quantities of Materials, Etc.; Back Filling; Bank Protection; Bending Tests; Bond; Built Members; Caissons Sunk by Pneumatic Process; Cast Iron; Cast Steel; Cement; Closing Thoroughfares; Coffer-Dam Work; Company; Composition of Rolled Steel; Concrete; Concrete Piers and Abutments; Construction; Contract; Damages; Defective Work; Depths of Foundations; Directions to Contractor; Drawings; Drifting Tests; Dry Surfaces in Concrete; Elastic Limits; Elongation; Encountering Obstacles; Engineer; Excavation; Extras; Eyebars; False-work; Field Riveting; Filling Column Feet; Final Inspection; Floors; Fracture; General Description; General Provisions on Methods of Testing; Granitoid; Hauling over Company's Lines; Identification; Inspection; Interference with Traffic; Liquidated Damages; Location; Loss of Metal; Metal; *Modus Operandi* of Construction; Name-Plates; Number of Test Pieces; Paint; Painting; Payments; Pile Foundations; Piles; Pin-Holes; Pin Metal; Pins; Position of Piers, Pedestals, and Abutments; Prices of Materials; Punching and Reaming; Reduction of Area; Re-Entrant Corners; Removal of Old Piers; Responsibility for Accidents; Return of Papers; Rivet-Holes; Rivets; Rolled Steel; Rollers; Routing of Materials; Scope of Contract; Sheared Edges; Shipping; Spirit of the Specifications; Steel Cutting Edges; Strictness of Inspection; Tenders; Tensile Strength; Tests of Full-Sized Eyebars; Tests of Full-Sized Members or Details; Timber;

Time of Completion; Turn-Buckles, Nuts, Threads, and Washers; Turned Bolts; Use of Old Rails; Variation in Weight; Workmanship; Wrought Iron.

Although I have omitted ten headings that simply enumerate the various crossings, the list I have just read contains nearly one hundred clauses, only seventeen of which may properly be termed general. The latter I shall now proceed to read and discuss in the order in which they appear in this particular set of specifications.

ADHERENCE TO SPECIFICATIONS.

All the work herein outlined is to be done in strict accordance with the specifications, the accompanying plans, and such instructions as may be given from time to time by the Company's engineers. Bidders are hereby warned that they will be held strictly to the spirit of these specifications, and that it will be bad policy for anyone to bid with the expectation that concessions will be made after the contract is closed, in order that the work may be cheapened; for while the Company's engineers desire to aid the Contractors in every legitimate manner to do their work expeditiously and economically, at the same time they have given these plans and specifications the most thorough consideration, and know exactly what they need in respect both to design and to quality of materials and workmanship. On this account, bidders are respectfully requested not to complicate their tenders by putting in alternative bids based upon proposed changes in either plans or specifications, because such alternative bids will not be considered.

This clause, which is common to all of our specifications, was originated by me some ten years ago, in order to prevent bidders from trying to upset our plans and specifications by offering some of their own for the purpose either of cheapening the work or of giving the bidder an advantage over his competitors. Promoters of enterprises are too prone to listen to the specious arguments of bidders when they contend that they are better posted upon what is needed than are the engineers. Whenever the promoters permit themselves to be influenced by such arguments they are certain to come to grief. Contractors work for their own interests, and it is right that they should do so; but they ought not to claim that their advice is unprejudiced and is offered for the sole purpose of improving the construction; when they do, they are not speaking the truth. For many years I have had to struggle constantly and vigorously against such attempts of bidders and contractors to change my plans and specifications, and on more than one occasion I have had to take the stand that either the promoter must refuse to entertain the bidders' suggestions or that I must resign my position. In one of these instances there were involved some two million dollars' worth of work; and I came within an ace of losing the engineering on it by my absolute refusal to consider the fundamental changes in my plans and specifications that were proposed by the bidders. By adopting the preceding clause and by adhering strictly to its context I have, after many years, succeeded in preventing any more such attempts to upset my work. Of course, in minor matters when a contractor offers politely any reasonable suggestion tending toward the modification of my requirements, I am always ready to consider it, and I never refuse to accede to such a request, if it be proved that the change is either beneficial or at least not detrimental to the construction.

DRAWINGS.

As soon as practicable after the signing of the contract for rebuilding the structures, complete detail drawings will be furnished by the Engineer, and from these the Contractor is to prepare his working drawings, complying carefully therewith, and making no changes without the written consent of the Engineer. The working drawings are to be sent in triplicate for the approval of the Engineer, who will retain two sets and return the third after checking same and marking thereon any changes or corrections desired; after which a corrected set of working drawings shall be sent without delay by the Contractor to the Engineer. The approval of the said working drawings by the Engineer will not relieve the Contractor from the responsibility of any errors thereon.

The drawings furnished by the Engineer shall be checked carefully by the Contractor before beginning work. Should any errors be discovered, the Engineer's attention shall be called to same, and corrections will be made, after which the Contractor shall be responsible for all errors which may occur or which may have occurred. The Engineer shall have the right to alter as he may see fit the preliminary plans, if further investigation of the conditions affecting the proposed structure so warrant; and he shall be at liberty to make minor changes in all plans during construction without any charge being made for same by the Contractor, unless, in the opinion of the Engineer, the Contractor be really entitled to extra compensation on account of such changes.

The Contractor shall furnish without charge as many sets of working drawings as the Engineer and other officers of the Company may deem necessary for their use during construction or for record.

Should the Engineer prepare any working drawings, they shall be checked carefully by the Contractor; and, if any errors be discovered, the Engineer's attention shall be called thereto. After the proper corrections of these are made the Contractor shall be responsible for all errors which may occur or which may have occurred.

It may at first thought appear a little arbitrary to hold the Contractor responsible for any errors that there may be in the Engineer's plans, but a little consideration will show that, if there are any such errors, they ought to be discovered before work is started, and that, as the Contractor is to attend to the construction, he ought to make sure in advance that the entire scheme is correct in every particular; who is there, then, so suitable as he to do the checking and to correct the mistakes?

It is not a good plan for the Engineer to prepare shop drawings for metal-work, because no two shops have exactly the same method of making working drawings; those suitable for one manufacturing company would not be acceptable to another. It is therefore much better for the Engineer to draft complete detail plans, then submit them to the Contractor as a guide for the preparation of the shop drawings.

INSPECTION.

The inspection and tests of metal will be made promptly on its being rolled or cast, and the quality will be determined before it leaves the rolling mill or foundry. The inspection of workmanship will be made as the manufacture of the material progresses, and at as early a period as the nature of the work will permit.

All facilities for inspection of metal and workmanship shall be furnished by the Contractor; and the Engineer and his inspectors shall have free access to any of the work in which any portion of the metal is being made.

The Contractor shall give the Inspector due notice when any metal is ready for inspection. Any delay on the part of the Inspector shall be reported to the Engineer, but no material will be accepted which has not been passed upon by the authorized representative of the Engineer.

All other materials than metal used on the work shall be inspected after delivery at site, unless the Contractor shall elect to have any materials inspected elsewhere, in which case the said materials shall be inspected by the Engineer at the places designated by the Contractor; but all expenses connected with such inspection shall be borne by the Contractor, and shall be paid promptly from time to time upon presentation of bills for same.

The reason for stipulating that all materials excepting metal shall be inspected at the site, unless the Contractor elect to have the inspection done elsewhere at his own cost, is that without this restriction there would be no end to the expense to which an Engineer would be put in sending inspectors all over the country to stone quarries, cement manufactories, sand pits, lumber mills and forests.

FINAL INSPECTION.

Before the completed work on each bridge is accepted and paid for in full, the Contractor shall notify the Engineer in writing that it is ready for final inspection. Upon receipt of this notification, the Engineer will arrange to give the entire work on the said bridge a minute and thorough inspection, either in person or through a competent representative who has not been employed regularly on this special work. Any defects or omissions noted during this inspection must be made good by the Contractor, without extra charge, before the work will be accepted and paid for in full.

The reason for specifying that the final inspection shall not be made by the resident engineer is that no man can well check or inspect his own work, because he will be almost certain to overlook any errors or omissions that had previously escaped his notice.

DEFECTIVE WORK.

The Contractor, upon being so directed by the Engineer, shall remove, rebuild, or make good, without charge, any work which the said Engineer may consider to be executed defectively. The fact that any defective material in the structure had been accepted previously by the oversight of the Company's Engineers or Inspectors shall not be considered a valid reason for the Contractor's refusing to remove it or to make it good. And until such defective work is removed and made good, the Engineer shall deduct from the partial payments or the final payment, as the case may be, whatever sum for such defective work as may, in his opinion, appear just and equitable.

Many contractors object strenuously to the clause which forces them to remove and replace any defective work, claiming that anything which is once passed is accepted finally, and that if it has to be rebuilt, the extra work involved should be paid for by the Company. But if such an arrangement as this were to rule, it would act as an incentive for contractors to attempt to bribe the inspectors, and would leave the Company without recourse from the results of the latter's dishonesty.

DIRECTIONS TO CONTRACTOR.

In case that the Contractor shall not be present upon the work at any time when it may be necessary for the Engineer to give instructions, the foreman in charge for the time being shall receive and obey any orders that the Engineer may give.

The Contractor shall commence work at such points as the Engineer may direct, and shall conform to his directions as to the order and time in which the different parts of the work shall be done, as well as to the force required to complete the work at the date specified.

CLOSING THOROUGHFARES.

The Contractor and his employees shall so conduct their operations as not to close any thoroughfare by land or water without the written consent of the proper authorities of such thoroughfare.

RESPONSIBILITY FOR ACCIDENTS.

The Contractor shall assume all responsibility for accidents to men, animals, materials, and trains before the acceptance of the structure; and must remove at his own expense all false-work, rubbish, or other useless material caused by his operations; and such work shall be included as a part of the work to be performed. The Contractor shall place sufficient and proper guards for the prevention of accidents, and shall put up and maintain at night suitable and sufficient lights.

DAMAGES.

The Contractor shall indemnify and save harmless the Company against all claims and demands of all parties whatsoever for damages or compensation for injuries arising from any obstructions erected by the Contractor or his employees, or from any neglect or omission to provide proper lights and signals during the construction of the work.

ALTERATION OF PLANS.

The Engineer shall have the power to vary, extend, increase, or diminish the quantity of the work or to dispense with a portion thereof during its progress without impairing the contract, and no allowance will be made the Contractor except for the work actually done. In case any change involve the execution of work of a class not herein provided for, the Contractor shall perform the same, and shall be paid the actual cost thereof plus the percentage for profit agreed upon in the contract. In this case the Contractor must furnish the Engineer with satisfactory vouchers for all labor and material expended on the work.

STRICTNESS OF INSPECTION.

All materials and workmanship will be inspected thoroughly and carefully, and the Contractor will be held at all times to the spirit of the specifications; but nothing will be done by the Company's Engineers or Inspectors to give the Contractor needless worry or annoyance, the intent of both specifications and inspection being simply to obtain for the Company work that will be first class in every particular and a credit to everyone connected with its designing and construction.

This clause contains in a nutshell the entire code of ethics which should govern the Engineer in his dealings with the Contractor.

SPIRIT OF THE SPECIFICATIONS.

The nature and spirit of these specifications are to provide for the work herein enumerated to be fully completed in every detail for the purpose designed; and it is hereby understood that the Contractor, in accepting the contract, agrees to furnish any and every thing necessary for such construction, notwithstanding any omission in the drawings or specifications.

It may seem unfair to bind the Contractor to furnish things not called for in the specifications; but the clause is intended to cover only such things as are absolutely necessary for the work and which were evidently overlooked when the bidding papers were prepared.

PAYMENTS.

Payments for work shall be made as follows:

On or about the first day of the month the Engineer will estimate the value of the work done and materials furnished; and within twenty-five

(25) days thereafter, eighty-five (85) per cent. of the value thus determined, less previous payments, shall be paid to the Contractor in cash. Upon the completion of each bridge involved in the contract, and upon acceptance of same in writing by the Company, the balance due the Contractor for the said bridge shall be paid to the said Contractor in cash.

Before, however, the final payment on any bridge is made, the Contractor shall show to the Company satisfactory evidence that all just liens, claims, and demands of his employees, or of parties from whom materials used in the construction of the work may have been purchased or procured, are fully satisfied; and that the materials furnished and work done on the structure are released fully from all such liens, claims, and demands.

If, too, during the progress of the work, it appear that the Contractor's bills for labor and materials are not being paid, the Company shall have the right to withhold from the Contractor's monthly payments a sufficient sum or sums to guarantee itself against all losses from mechanics' and other possible liens, and to apply the said sum or sums to the payment of such debts.

Or, if during construction it appear to the Engineer that the Contractor is not making proper progress, the Company shall have the right, after giving the Contractor ten days' notice in writing, to undertake itself, either by administration or by letting a contract to other parties, the completion of the said work which is being thus neglected. Should the Company's work cost less than what the Contractor would have been paid, the difference shall be paid to the Contractor; but on the other hand, should it cost more, the difference shall be charged to the Contractor, and shall be taken out of the reserved fifteen (15) per cent., or out of the bond.

Under these circumstances the Company shall have the right to enter upon and take temporary possession of the plant, tools, materials, and supplies of the said Contractor or any part thereof. In case that the percentage of earnings withheld by the Company be insufficient to make good the deficit, the Company shall have the right to reimburse itself by the sale of the Contractor's plant; but otherwise the said plant shall be returned to the Contractor after the completion of the work.

The number of days that may elapse between the time of preparing the monthly estimates and the date of payment varies generally from ten to thirty according to the attendant conditions, it being necessary to allow time for the compilation of statistics, mailing of papers, distribution of estimates, and forwarding of checks.

The amount retained from each estimate by the Company until the completion of the entire contract is generally ten per cent. and never more than fifteen per cent.

It is one of the most important duties of the Engineer to make sure that his clients are protected against mechanics' and other liens upon the work, and he will have to be ever on the alert to ensure this when dealing with irresponsible or tricky contractors.

The handling of work by administration is generally rather expensive for the Company and burdensome to the Engineer; so it is to be avoided whenever possible.

EXTRAS.

No extras will be allowed unless they be ordered in writing by the Engineer. For extras so allowed the Contractor will be paid the actual cost to him plus ten (10) per cent. for profit. Satisfactory vouchers will be required from the Contractor for all extra labor and materials.

The question of extras is always likely to be a bone of contention between the Contractor and the Engineer; consequently the more fully it is covered in the specifications the better for both parties.

BOND.

The successful bidder will be required to give to the Company a satisfactory Surety Company Bond, in the sum of.....dollars, for the faithful performance of the contract and specifications and all the terms and conditions therein contained, and for the prompt payment of all material and labor used in the manufacture and construction of the structures, and to protect and save harmless the Company from all damages to persons or property, caused by the negligence or claim of negligence by the Contractor, his agents, servants, or employees in doing the work, or in connection therewith. Each bidder must state in his tender the name of the Surety Company that he offers for furnishing this bond.

CONTRACT.

As soon as possible after the award of the contract is made, a contract similar to that outlined on the accompanying form will be presented in duplicate to the successful bidder for his signature, after which both copies will be signed by the Company, and one of them will be given to the said successful bidder.

RETURN OF PAPERS.

All papers submitted to bidders, excepting only those of the successful bidder, are to be returned to the Consulting Engineers upon demand.

The reason why the unsuccessful bidders are required to return the papers submitted to them for tendering is that several copies of the plans and specifications will be required later for those prosecuting the work, and this return of papers will effect an economy in copying.

Before leaving the subject of general clauses, I shall quote a few found in the contract (of which the specifications form a part). The division of the entire list of general clauses between the specifications and the contract is purely arbitrary. My firm has a certain form of contract of its own, which will apply to any and all of our specifications by simply filling in the blank spaces. It is from this form that I am about to quote certain paragraphs in order to complete my list of general clauses that will apply to all engineering specifications.

Sixth.—All material paid for by the party of the first part shall be deemed to have been delivered to, and to have become the property of the said first party, but the party of the second part hereby agrees to store it and to become responsible therefor during the continuance of this agreement.

The object of this clause is to make the Contractor responsible for the care and insurance of all materials delivered and partially paid for. Without some such provision the Company would have to stand all losses from flood, fire, and theft before the completion and acceptance of the structure.

Seventh.—In case the party of the first part, notwithstanding the failure of the party of the second part to complete its work within the time specified, shall permit the said second party to proceed and continue and complete the same as if such time had not elapsed, such permission shall not be deemed a waiver in any respect, by the first party, of any forfeiture or liability for damages or expense thereby incurred, arising from such non-completion of said work within the time specified, and covered by the "Liquidated Damages" clause of the specifications; but such liability shall continue in full force against the said second party, as if such permission had not been granted.

Without some such clause as this the Contractor when allowed to exceed his contract time might claim immunity from liquidated damages, and thus render that clause of the specifications null and void.

Eighth.—No change or alteration shall be made in the terms or conditions of this agreement without the consent of both parties hereto in writing; and no claim shall be made or considered for any extra work, unless the same shall be authorized and directed in writing by the Engineer.

Ninth.—In the event of any delay in completing the work embraced in this contract, the party of the second part shall be entitled to no extra compensation on account of such delay; as it is hereby assumed that in submitting its tender it took its chances for the occurrence of such delay.

This is an unusual clause in engineering contracts, having been originated by me some years ago. The usual objection to it is that it is entirely one-sided, which cannot be denied. It is certainly likely to be of great advantage to the Company, as the latter is often tied up by litigation and sometimes from want of sufficient funds to prosecute the construction continuously or as rapidly as desired. Of course the Engineer in applying this clause must use his judgment and sense of equity to make sure that it does not involve any real hardship for the Contractor. Its main object is to prevent the latter from claiming exemption from all liquidated damages or from demanding extra compensation on account of trifling delays caused either by the Company or by circumstances beyond the Company's control.

Tenth.—The party of the second part hereby agrees that it will not assign or sublet the work covered in this contract, or any portion of it, without the written consent of the party of the first part, but will keep the same within its control.

Eleventh.—The decision of the Engineer shall control as to the interpretation of drawings and specifications during the execution of the work thereunder; but if either party shall consider itself aggrieved by any decision, it may require the dispute to be finally and conclusively settled by the decision of three arbitrators, the first to be appointed by the party of the first part, the second by the party of the second part, and the third by the two arbitrators thus chosen. By the decision of these three arbitrators, or by that of a majority of them, both parties to this agreement shall be finally bound.

It is seldom that this arbitration clause is resorted to, for the Engineer's decisions are almost invariably just and reasonable. Only once in my entire career has it been put in force on my work, and, as in this instance there was too good an understanding between the promoter of the enterprise and the dealer who furnished the rejected materials, I lost the case.

Twelfth.—As, according to the terms of the accompanying specifications, which form a part of this contract, the party of the second part is to indemnify the party of the first part against all liability or damages on account of accidents occasioned by the omission or negligence of itself, or its agents, or its workmen during the continuance of this agreement, and is to pay all judgments recovered by reason of such accidents in any suit or suits against the party of the first part, including legal costs, court and other expenses; it is hereby agreed that the party of the second part shall be promptly and duly notified in writing by the party of the first part of the bringing of any such suit or suits, and shall be given the option of assuming the sole defense thereof.

This provision is entirely in the Contractor's favor, but the point involved is one of simple equity; for if he is to pay all damages he certainly ought to be allowed to handle the legal fight in his own way.

And now I shall quote some specific clauses merely to illustrate their general style and character, for it is obvious that it would be impracticable in a lecture like this to attempt to cover all the specific clauses for even one class of construction—much less for all classes.

The following clauses are taken from the same set of specifications as before:

SCOPE OF CONTRACT.

The contract will cover the following:

1st. Removal of old spans, marking properly all the pieces of same, and piling these near the site as per the instructions of the Engineer.

2d. Removal of old piers and portions of old piers, and distributing the removed masonry as rip-rap around the piers of the same bridges from which the said masonry was taken, all in accordance with the instructions of the Engineer.

3d. The furnishing of all materials (excepting old rails) for and the rebuilding of the tops of old piers that are to be repaired.

4th. The furnishing of all materials (excepting old rails) for and the building of all new piers and abutments.

5th. The furnishing of all the materials (excepting track rails and their fastenings) for and the building complete of all the new spans required, including the timber floor.

6th. Providing all materials for and building all falsework to carry the old fixed spans which are to be left in, while the supporting piers are being repaired, and removing the said falsework as soon as the Engineer gives directions for such removal.

7th. Laying of track on all new spans and connecting same properly to the approaches.

Let me call your attention to the clearness and conciseness with which the various items in this clause are stated, and caution you when preparing specifications of your own to be just as clear in everything relating to "Scope of Contract," for this is one of the most important clauses of any set of specifications.

HAULING OVER COMPANY'S LINES.

There will be no charge for hauling over the Company's lines any of the Contractor's men, materials, or plant.

APPROXIMATE QUANTITIES OF MATERIALS, ETC.

The following are the approximate quantities of materials, etc., in the ten (10) structures. They will be used in comparing tenders for awarding of contract, but are not to be considered in any way binding upon the Company or upon its Engineers:

Structural steel in new pin-span, erected and painted	1,313,000	lbs.
Structural steel in new plate girder spans, erected and painted	6,586,000	lbs.
Timber in railway floors	400	M. feet, B. M.
Length of single track to be laid	4,300	lineal feet.
Old spans to be removed	3,311	lineal feet.
Old masonry to be removed	1,612	cubic yards.
Mass in caisson and crib of pneumatic pier	1,360	cubic yards.
Mass in cribs or bases of all other piers	2,800	cubic yards.
Concrete in bases of all abutments (no allowance being made for cost of excavation, cofferdams, pumping, bailing, etc.)	2,100	cubic yards.
Concrete in shafts of piers and abutments	13,200	cubic yards.
Piles in place, below bottoms of cribs	16,200	lineal feet.
Length of old spans to be supported on falsework	473	lineal feet.

There will be no allowance for excavation or for back filling, as the cost of these items must be covered by the schedule prices for mass of foundations and piles in place.

Neither will there be any allowance made for cost of removing old wooden trestle, as the Contractor will utilize the same for false-work to support the new girders.

Neither will there be any allowance made for the placing as rip-rap around the piers the masonry stones removed from the existing piers, as this must be covered by the schedule price for the removal of masonry.

Although the quantities given under this heading are generally approximate, it is very important, nevertheless, that they be filled out; because, in the first place, they give bidders a proper conception of the magnitude of the work, and, in the second, they afford a means of comparing bids on a basis that is perfectly fair to all competitors.

INTERFERENCE WITH TRAFFIC.

The Contractor must so conduct all of his operations as not to interfere at all with the passage of the Company's trains; and he must take every precaution against accidents to the said trains caused by his operations. Should any accidents occur by reason of such operations, either directly or indirectly, the Contractor will be held responsible both pecuniarily and morally for the results of such accidents.

The importance of this clause to the railroad company cannot be overestimated. Wherever bridges are to be constructed on lines in operation this clause should under no circumstances whatsoever be omitted.

REMOVAL OF OLD PIERS.

In taking down existing piers which are not to be rebuilt, small charges of explosives may, with the consent of the Engineer, be used; but none may be employed for removing the tops of piers that are to be rebuilt. In the latter the greatest of care must be taken not to injure any of the masonry that is to be preserved.

All masonry that is removed from the old piers and abutments must be disposed of as rip-rap for piers, or otherwise as directed by the Engineer.

METAL.

Unless otherwise specified, all metal shall be medium steel, excepting only that rivets and bolts are to be of soft steel and adjustable members of either soft steel or wrought iron.

Except for the washers for floor bolts, cast iron will not be allowed to be used in the superstructure, cast steel being employed wherever important castings are necessary.

ROLLED STEEL.

All steel shall be manufactured by either the acid or the basic open-hearth process, and must be uniform in character for each specified kind. Any attempt to substitute Bessemer or any other steel for the open-hearth product will be considered a violation of the contract and a good and sufficient reason for cancelling the same.

All plates shall be rolled from slabs. These slabs shall be made by a separate operation, by rolling an ingot and cutting off the scrap. The original ingot shall have at least twice the cross-sectional area of the slab, and the latter shall be at least six (6) times as thick as the plate.

All finished material coming from the mills must be free from seams, flaws, or cracks; and must have a clean, smooth finish.

GENERAL PROVISIONS ON METHODS OF TESTING.

Rivet rods and other rounds are to be tested in the form in which they leave the rolls, without machining.

Test pieces from angles, plates, shapes, etc., shall be rectangular in shape, with a cross-sectional area of preferably about one-half (½) of a square inch, but not less, and shall be taken so that only two sides are machine finished, the other two having the surface which was left by the rolls.

Should fracture occur outside of the middle third of the gauge length, the test is to be discarded as worthless, if it falls below the standard.

If any test piece have a manifest flaw, its test shall not be considered.

In case that one piece fall slightly below the requirements in any particular, the Inspector may allow the retesting of the lot or heat by taking four (4) additional tests from the said lot or heat; and if the average of the five shall show that the steel is within the requirements, the metal may be accepted; otherwise it shall be rejected.

Drillings for chemical analysis may be taken either from the preliminary test piece or from the finished material.

The speed of the machine for breaking test pieces shall not be less than one-quarter (¼) inch per minute nor more than three (3) inches per minute.

Material which is to be used without annealing or further treatment is to be tested in the condition in which it comes from the rolls. When the material is to be annealed or otherwise treated before being used, the specimens representing such material may be similarly treated before testing; but they shall also give standard elongation, reduction, and fracture before annealing.

BENDING TESTS.

Specimens of soft steel shall be capabie of bending to one hundred and eighty (180) degrees and closing down flat upon themselves, without cracking, when either hot, cold, or quenched.

Specimens of medium steel, when heated to a dark orange and colored in water at seventy (70) degrees Fahrenheit, or when cold or hot, shall be capable of bending one hundred and eighty (180) degrees around a circle whose diameter is equal to the thickness of the test-piece, without showing signs of cracking on the convex side of the bend.

DRIFTING TESTS.

Punched rivet holes in medium steel, pitched (2) diameters from a sheared edge, must stand drifting until their diameters are fifty (50) per cent. greater than those of the original holes, and must show no signs of cracking the metal.

FRACTURE.

All broken test pieces for both classes of steel must show a silky fracture of uniform color.

WORKMANSHIP.

All metal shall be straightened carefully before being turned over to the shops.

All workmanship shall be first-class in every particular, and all portions of metal-work exposed to view shall be neatly finished.

All idle corners of plates and angles, such for instance as the ends of unconnected legs of angle lacing, shall be neatly chamfered off at an angle of about forty-five (45) degrees, so as to give a sightly finish to the work and to avoid bending of said corners during shipment and erection.

As far as practicable, all parts shall be so constructed as to be accessible for inspection and painting.

All punched work shall be so accurately done that, after the various component pieces are assembled and before the reaming is commenced, forty (40) per cent. of the holes can be entered easily by a rod of a diameter of one-sixteenth ($\frac{1}{16}$) of an inch less than that of the punched hole; eighty (80) per cent. by a rod of a diameter of one-eighth ($\frac{1}{8}$) of an inch less than same; and one hundred (100) per cent. by a rod of a diameter one-quarter ($\frac{1}{4}$) of an inch less than same. Any shop work not coming up to this requirement will be subject to rejection by the Inspector.

These requirements for accuracy in punching were formulated some six years ago by Mr. Frank C. Osborn, C. E., of the Osborn Engineering Co., and by me, working jointly. They are by no means too severe, and yet are rigid enough to ensure truly first class shop work. It is only the good shops, though, that can comply with such requirements.

FIELD RIVETING.

All field riveting shall be done by pneumatic riveters of a type to be approved by the Engineer, except in places where it is impracticable to use the apparatus, in which cases hand riveting will be permitted.

The quality of pneumatic riveting is far superior to that of hand riveting and but little inferior to that of the machine riveting done in the shops. The use of the pneumatic riveters for field work has permitted the adoption of much longer riveted spans than were built when all field riveting was done by hand. Not only are the rivets driven by the pneumatic machine much tighter, but more than twice as many can be driven per day with the same force of men as compared with hand-driven rivets.

PUNCHING AND REAMING.

All rivet-holes in steel work, if punched, shall be made with a punch one-eighth ($\frac{1}{8}$) inch in diameter less than the diameter of the rivet intended to be used, and shall be reamed to a diameter of one-sixteenth ($\frac{1}{16}$) inch greater than that of the said rivet.

Before this reaming takes place, all the pieces to be riveted together shall be assembled and bolted into position, then the reaming shall be done; for one of the principal objects of this clause in relation to sub-punching is to insure the correct matching of rivet holes and the avoidance of holes of excessive diameter. The said clause also insures the removal of most, if not all, incipient cracks started by the process of punching.

All reaming is to be done by means of rigid twist-drills, the use of tapered reamers being prohibited, except where rigid twist-reamers cannot be employed. All holes must be at right angles to surface of member, and all sharp or raised edges of holes under heads must be slightly rounded off before the rivets are driven.

All holes for field rivets, excepting those for lateral or sway bracing, when not drilled to an iron template, shall be reamed while the connecting parts are temporarily assembled.

Punching shall not be permitted in any piece in which the thickness of the metal exceeds the diameter of the cold rivet that is to be used; but all such pieces shall be drilled solid.

For the last ten years I have been fighting hard to have all important metal sub-punched and reamed, and have succeeded as far as my own work is concerned; for the contractors have at last ceased telling our clients how much money could be saved on the work by omitting the sub-punching and reaming. If anyone has any doubts about the necessity for this treatment of the metal, he can set them finally at rest in one of two ways—by reading my *résumé* of the discussions on my paper upon "Elevated Railroads," published in the " Transactions of the American Society of Civil Engineers," or by inspecting in the shops before the reaming is done a lot of assembled metal, running his finger into a number of the holes, and noting the great irregularities that the rivets will have to fill, if the holes be punched full size.

SHIPPING.

All parts shall be loaded carefully so as to avoid injury in transportation, and shall be at the Contractor's risk until erected and accepted.

In shipping long plate-girders great care is to be taken to distribute the weight properly over the two cars that support them and to provide means for permitting the cars to pass around curves without disturbing the loading. In both the handling and the shipment of metal-work every care is to be taken to avoid bending or straining the pieces or damaging the paint. All pieces bent or otherwise injured will be rejected.

The preceding clauses have all related to the superstructure of bridges; those immediately following will relate to the substructure.

POSITION OF PIERS, PEDESTALS AND ABUTMENTS.

All piers, pedestals, and abutments, when finished, must be in exact position and to exact elevation; and all anchor bolts therein must be located with the greatest exactness in respect to both horizontal position and elevation.

The Contractor must provide all guide-piles, anchors, cables, frames, and forms that may be required to insure the result.

The placing in exact position of all piers is one of the most difficult feats that the substructure contractor has to accomplish; consequently it is evident that this requirement is an absolute necessity.

DEPTHS OF FOUNDATIONS.

All cribs, footings, and caissons are to be sunk to the depths shown on the Engineer's plans or to such other depths as the Engineer may deem necessary as the work progresses.

The data furnished to bidders by the Engineer regarding depths of foundations or of bed rock are to be considered as merely approximate; and bidders must assume the risk of having to go a greater or less depth without altering in any way their schedule prices. If, however, the Engineer consider that the Contractor is really entitled to extra compensation on account of material variation from the data furnished, such extra compensation will be allowed, but the amount thereof shall be determined solely by the Engineer.

If, too, during the progress of the work, the Engineer deem that further investigations concerning the elevations of bed rock or quality of materials for foundations are necessary, the Contractor shall make at his own expense, under the direction of the Engineer, all the borings or similar investigations which the latter may consider to be requisite.

ENCOUNTERING OBSTACLES.

Bidders must figure on taking their chances of encountering logs, boulders, and other obstacles under the river bed at the pier sites; and the Contractor must provide himself with all the necessary tackle and apparatus for handling the same. There will be no extra price allowed because of the difficulty in sinking, or in driving through, or in removing said obstacles.

Some contractors complain that this clause is too severe, in that it places upon them the entire responsibility and risk involved in case of meeting with unexpected obstacles; nevertheless it is both fair and necessary. If the contractor were paid extra on account of obstacles, there would be no end to his claims for increased compensation, and the amounts of these claims might be excessive, because he would probably fail to make at the outset proper provision for removing all obstructions, while, if the *onus* were on him, he would undoubtedly provide everything necessary.

PILE FOUNDATIONS.

Where piers and abutments are to rest on piles, the earth is to be excavated to the depth required, the boxing timber is to be put in, if any be called for on the plans or by the Engineer, then the piles are to be driven to the satisfaction of the Engineer, and cut off at the proper elevation, then the earth that has risen between the piles is to be removed, and the bed is to be rammed, if the Engineer so direct. The length and penetration of all piles are to be determined by the Engineer.

If it be practicable to pump out the water in the pit and keep the latter clear of same without injury to the unset concrete, this is to be done while the concrete is being tamped around the piles to within two (2) feet of the tops thereof, and until the concrete has set; otherwise, concrete of the same kind as hereinafter specified for the tops of concrete piers is to be placed between and around the piles by means of a trèmie, being carried up to the height just specified; and after the same has set the water is to be pumped out, and the remainder of the footing is to be built of ordinary concrete laid in the dry.

CONCRETE PIERS AND ABUTMENTS.

All piers and abutments are to be built of broken stone concrete; but the Contractor will be permitted to mix therewith a portion of clean gravel in order to reduce the percentage of voids in the broken stone.

The proportions for concrete without gravel for all interiors and footings of piers and abutments shall be as follows:

1 part of Portland cement.
3 parts of clean, coarse, sharp sand.
5 parts of broken stone to pass a two and one-half (2½) inch iron ring.

Where gravel is mixed with the stone, the proportions for the said concrete are to be as follows:

3 parts of sand as above.
5 parts of mixed broken stone and gravel, with enough cement to more than fill all voids in the mixture by ten (10) per cent., and in no case less than one barrel (380 lbs. net) of cement per cubic yard of concrete. The determination of the volume of voids shall be left to the Engineer.

For exterior concrete work and for all concrete to be deposited, before setting in water, the proportions are to be as follows:

1 part of Portland cement.
2 parts sand.
3 parts of fine broken stone, to pass through a three-quarter (¾) inch iron ring.

The exterior six (6) inches of all faces of piers and abutments that are exposed to the atmosphere or to water, are to be built of the rich small-stone concrete just described; and this is to be mixed and placed simultaneously with the other concrete, so that there shall be no division whatever, but a perfect bond between the two classes of concrete.

Suitable forms of timber properly lined with oiled sheet iron must be provided to give the constructions the exact dimensions and the finish shown on the drawings. Care must be taken to make all forms strong enough to resist the ramming of the concrete without bulging out or in any way changing their position.

No forms are to be removed until after the concrete deposited therein has stood thirty-six (36) hours or as much longer as the Engineer may deem necessary.

The exterior concrete is to be tamped solidly against the sheet-iron forms, so that there will be no voids on the exterior surface, which is to be left permanently as it comes from the moulds, unless the Engineer deem that the surface is too rough, in which case the Contractor must put on a smooth two-to-one mortar finish to the satisfaction and acceptance of the Engineer.

All interior and footing concrete is to be deposited in layers not exceeding nine (9) inches in thickness, and each layer is to be thoroughly rammed.

DRY SURFACES IN CONCRETE.

Should, during construction, any surfaces of the concrete be allowed to harden or dry before the other concrete is placed thereon, they shall be swept perfectly clean with brooms, then wetted thoroughly with clean water so as to make a perfect contact between the old and the new work, and thus insure that the concrete shall be truly monolithic. The forming of such dry surfaces shall, however, always be prevented if practicable.

CEMENT.

All cement used on the work must be Portland cement of the very best quality obtainable, equal in every respect to the best brands of American and European manufacture, and delivered at site in strong, close, barrels, well lined with paper so as to be reasonably secure from air and moisture, unless the Engineer give the Contractor written permission to deliver it in bags.

Each barrel shall be labeled with the name of the brand, place made, and name of manufacturer.

The cement shall be ground so fine that at least ninety-seven (97) per cent. in weight will pass a standard sieve of five thousand (5,000) meshes to the square inch, and so that at least ninety (90) per cent. will pass a standard sieve of ten thousand (10,000) meshes per square inch.

When moulded neat into briquettes and exposed three (3) hours, or until set, in air and the remainder of twenty-four (24) hours in water, it shall develop a tensile strength of from one hundred (100) to two hundred and fifty (250) pounds per square inch. When moulded neat into briquettes, after exposure of one (1) day in air and six (6) days in water, it shall develop a tensile strength of from two hundred and fifty (250) to five hundred (500) pounds per square inch; and after exposure of one (1) day in air and twenty-seven (27) days in water, it shall develop a tensile strength of from four hundred (400) to six hundred (600) pounds per square inch. It shall be an eminently slow setting cement, must develop its strength gradually, and must show no drop therein. When moulded neat into pats with thin edges and left to set in either air or water, whether on glass or not, the said edges must show no signs of checking. The cement shall withstand properly the standard twenty-four (24) hour boiling test for Portland cements.

The cement, when mixed neat with about twenty-two (22) per cent. of water to form a stiff paste, shall after thirty (30) minutes be indented perceptibly by the end of a wire one-twelfth ($\frac{1}{12}$) inch in diameter, loaded to weigh one-quarter ($\frac{1}{4}$) pound.

The hard set, determined similarly with a wire one twenty-fourth ($\frac{1}{24}$) inch in diameter and loaded so as to weigh one pound, shall not occur in less than three (3) hours.

Briquettes mixed in the proportion, by weight, of one part of cement to three (3) parts of sand, and kept one day in air and the remaining time in water, shall show a tensile strength of from one hundred (100) to one hundred and fifty (150) pounds per square inch after twenty-eight (28) days.

Briquettes left in moulds and placed in water immediately after mixing must harden to the satisfaction of the Engineer, so as to prove the fitness of the cement for setting under water. This test may be made a comparative one by pitting the cement tested against brands of established reputation. Any cement not hardening under water to the satisfaction of the Engineer will be rejected. Cement must work well under the trowel; otherwise it will not be accepted.

In any case, the cement adopted must first be approved by the Engineer.

The Contractor shall provide a suitable building for storing the cement, in which the same must be placed before being tested. The Engineer shall be notified of the receipt of cement for testing at least two (2) weeks before it is required for use, and the Inspectors may take a sample from each package for the said testing.

Any cement that has caked so as, in the opinion of the Engineer, to be injured shall be rejected, and shall be removed immediately by the Contractor from the neighborhood of the site, in order to avoid all possibility of its being used on the work.

BACK-FILLING.

As soon as the masonry or concrete work thereon is completed, the space around each shore pier and abutment shall be filled with earth, preferably clay, thoroughly dampened, and well rammed in layers not exceeding six (6) inches in thickness. There will be no direct payment for this back-filling, as the cost is to be covered by the price for concrete.

LIQUIDATED DAMAGES.

For each day of delay beyond the date set in the contract for completing the Big Brazos River and Brushy Creek No. 1 bridges, all in accordance with the plans, specifications, and directions of the Engineer, the Company shall withhold permanently from the Contractor's total compensation the sum of one hundred dollars ($100.00.)

For each day of delay beyond the date set in the contract for completing the remaining eight (8) bridges, all in accordance with the plans, specifications, and directions of the Engineer, the Company shall withhold permanently from the Contractor's total compensation the sum of one hundred dollars ($100.00.)

The amounts thus withheld shall not be considered as a penalty but as liquidated damages fixed and agreed to by the contracting parties.

Let me call your attention to the term "Liquidated Damages," which is now employed instead of the older term "Penalty." If the latter were used it would be illegal, as the courts hold that no individual or corporation has the right to enforce a penalty, such enforcement being within the jurisdiction of the law only, but liquidated damages fixed beforehand can be collected.

TENDERS.

Each bidder shall tender as follows:

1st. For removal of old spans, marking all the pieces of same, and piling these as per instructions of the Engineer, ... dollars per lineal foot of span removed.

2nd. For removal of old masonry and distributing same, ... dollars per cubic yard.

3rd. For concrete in shafts of new piers and rebuilt portions of old piers, ... dollars per cubic yard.

4th. For mass in place of pneumatic pier, including excavation, ... dollars per cubic yard.

5th. For mass in place of foundations for all piers and abutments, including those portions of piles imbedded in the concrete, and including the excavation, ... dollars per cubic yard.

6th. For those portions of piles in place below the concrete of the foundations, ... cents per lineal foot of pile.

7th. For all structural metal in superstructure of pin-connected span, erected and painted, ... cents per pound.

8th. For all structural metal in all other spans, erected and painted, ... cents per pound.

9th. For floor timber in place, excluding dressing and all other wasted timber, ... dollars per M. feet B. M.

10th. For laying rails, ... cents per lineal foot of track.

11th. For false-work under the existing spans that are to be left in the reconstructed bridges, ... dollars per lineal foot of span.

For all other items not covered in this list the Contractor is to be paid the actual cost to him thereof plus ten (10) per cent. for his profit. He must, however, in such cases furnish vouchers satisfactory to the Engineer for all materials and labor involved in such extra work or construction.

Tenders are to be sent in sealed envelopes to the undersigned Consulting Engineers, New Nelson Building, Kansas City, Mo. They will be received up to noon of Thursday, July 17th, 1902.

The Company reserves the right to reject any or all bids.

It will be noticed that all items of work are to be paid for at schedule rates, and that lump-sum payments are avoided. This is by far the better and more equitable method of compensation; because, if the final quantities vary from those bid upon, no harm will be involved, the Contractor being paid for only what he actually does. If the lump-sum basis of payment be employed, the Contractor will be constantly tempted to cut down the quantities of materials furnished, but when these are paid for by schedule prices no such temptation can exist.

The following are a few specific clauses from our "Specifications for Lighthouses at Jutias Cay and Punta Gobernadora, on Colorados Reef, Island of Cuba." I have chosen only such items as are characteristic of lighthouse construction.

GENERAL DESCRIPTION.

LIGHTHOUSE AT JUTIAS CAY.

This Lighthouse will be located on the Northeast extremity of Jutias Cay, at a distance of about eighty-seven (87) meters from the water's edge. The location is well protected from the action of the waves by a reef in front and by the growth of mangroves. The height of the ground at the site is about nine-tenths (0.9) of a meter above the sea level.

The soundings made at the site show that the ground is composed of fine sand for a depth of from four (4) to five (5) meters, then of sand, shells, and coral rock for a depth of about eight-tenths (0.8) of a meter, and this is underlaid with sand and shells, in which are imbedded pieces of coral rock that become more abundant as the depth increases. It is intended that the screw piles shall rest on this layer. These piles are of steel shafting fitted with cast iron screw points as shown on the drawings.

The light for this structure will be a fixed one. The tower will be constructed of eight (8) steel columns arranged in the form of an octagonal pyramid, the long diameter of which will be fifty-six (56) feet at the base and fifteen (15) feet at the top. These columns are to be thoroughly braced in all directions with steel struts and diagonal rods as shown on the drawings.

There will be a house located at the base of the tower, and a watch-room located in the top of same. There will also be a stairway extending from the base to the watch-room floor, enclosed by a mantel. These enclosures are to be constructed of steel plates, and the interior walls are to be plastered on expanded metal lath.

LIGHTHOUSE AT PUNTA GOBERNADORA.

This structure will be placed on the main land at a point known as Punta Gobernadora, about six (6) miles west of Bahia Honda. The distance from this tower to the edge of the water will be about one hundred and fifty (150) meters. The site is protected from the action of the waves by reefs on the outside. The formation here is an extensive bed of limestone-coral rock, and the surface is practically level.

The light for this structure will be a movable one.

In all other respects the superstructure will be the same as described previously for the lighthouse at Jutias Cay.

FOUNDATIONS.

FOR LIGHTHOUSE AT JUTIAS CAY.

The foundation for this structure will consist of nine (9) screw piles, as shown on Sheet No. 2, eight (8) of which are placed in the form of an octagon around the axis of the ninth (9th) or central pile. The long diameter of the octagonal base is to be fifty-six (56) feet, and each of the sides twenty-one (21) feet and five and one-eighth (5⅛) inches.

These piles are to be formed of solid steel shafts eight (8) inches in diameter, at the lower end of each of which is to be fitted a cast iron screw, the blades thereof to be four (4) feet in diameter. The lower end of the screw is to finish in a point.

The exact depth to which these piles must go has not been determined, but it will be from eighteen (18) feet to twenty-five (25) feet below the surface of the ground. The Contractor must provide twenty-five (25) feet of shaft and a pile cutter and a screw cutter, so as to cut off the piles and thread them at the proper height after screwing them down as far as they will go.

After the piles are in place and the tops are cut to the proper elevation, concrete pedestals, as shown on Sheet No. 2, are to be placed around them; and on these pedestals screwed to the tops of the piles, will rest the shoes for the steel columns of the tower.

The elevations and dimensions for these foundations are given on Sheet No. 2.

STEEL STAIR MANTEL.

The spiral stairs will be enclosed in a steel cylinder, the axis of which is coincident with the axis of the tower. The diameter of this steel cylinder will be seven (7) feet. It is to be formed of steel plates one-quarter (¼) of an inch in thickness, the larger dimensions of which are to be arranged vertically with the edges abutting and the joints spliced with four (4) inch by one-quarter (¼) inch plates placed on the inside.

The lower end of this cylinder is to rest on the center pile and its concrete pedestal. All rivets in the stairway cylinder are to be one-half (½) inch in diameter. In the lower section of the cylinder a door is to be placed, and at a height of three (3) feet above each stairway landing there is to be fitted a cast iron window frame. All windows are to be arranged as nearly as practicable at points ninety (90) degrees apart around the cylinder, and they must come about midway between the two columns on that side of the pyramid.

The inside of the stairway cylinder is to be provided with angles for attaching three-quarter (¾) inch channels and expanded metal lath, as the entire inside of the cylinder is to be finished with plaster.

SPIRAL STAIRS.

The spiral stairs will consist of one hundred and forty-eight (148) risers, including eight (8) quarter (¼) circle landings, which divide the ascent into nine (9) flights, eight (8) of which are twelve (12) feet nine

(9) inches each in height, and containing seventeen (17) risers of nine (9) inches each, and one flight of nine (9) feet, containing twelve (12) risers of nine (9) inches each.

The steps are to be of cast iron, the extreme radius of each being three (3) feet. Each step comprises a tread of twenty-two and one-half (22½) degrees of the circle, between the centers of the one-half (½) inch bolts which will secure the steps to each other.

The inner end of each step is provided with a hub six and five-eighths (6⅝) inches outside diameter, which must be faced on its upper and lower ends to exactly nine (9) inches deep, and must be bored out to five and one-half (5½) inches in diameter so as to fit snugly over the newel pipe.

The treads are one-half (½) inch thick and are perforated with lozenge-shaped openings one (1) inch wide. The gratings are one-half (½) inch wide, and at their inner sections the steps are studded with lozenge-shaped projections to prevent slipping; and for the same reason a half-round bend one-eighth (⅛) inch high is raised along the front edge of each step.

The bolt sleeves at the front of each step are to be nine (9) inches high and deeply counter-sunk on the upper side for the heads of the stair-bolts.

All surfaces of contact between the sleeves of the adjoining steps must be planed.

NEWEL POST.

The newel post will be made of double-strength, wrought-iron water pipe, five (5) inches inside diameter, and turned on the outside to a diameter of five and one-half (5½) inches. At each joint the ends must be faced so as to give perfect contact, and the joints must be so arranged as to bring them midway of the length of the hubs of the steps. On the inside the pipe must be spliced with a threaded coupling.

The newel pipe should be made in seven (7) lengths of about sixteen (16) feet each, as nearly as may be, to bring the joints as stated above.

The base of the newel pipe will be provided with a steel flange, which will be tap-bolted to the cast iron base at center.

Throughout the whole height of tower the newel must stand perfectly plumb.

In the case of the Punta Gobernadora Lighthouse the cord of the revolving apparatus will be run through the center of the newel pipe, and pulleys near the upper and lower ends of the pipe must be provided.

The upper end of the top section of the newel pipe will extend a short distance into the hub of the watch-room floor.

DWELLING HOUSE.

The entire space included between the columns at the base of the tower is to be enclosed with steel walls so as to form a dwelling. This space is to be divided into nine (9) outside rooms and an inner court. The walls and roof of this building are to be of one-quarter (¼) inch steel plates of the style and dimensions indicated on Sheet No. 5. All rivets are to be one-half (½) inch in diameter unless otherwise noted on the drawings.

The floor will be of concrete, supported on No. 16 expanded metal and steel I-beams. There will be three and one-half (3½) inches of broken stone or cinder concrete, mixed in the proportion of one (1) part of Portland cement, three (3) parts of clean, sharp sand, and five (5) parts of broken stone or cinders to pass a one and one-half (1½) inch iron ring. On this concrete base there is to be laid one (1) inch of cement finish, mixed in the proportion of one (1) part of Portland cement and one (1) part of clean, sharp sand. The entire surface is to be floated to a smooth, even finish.

All partitions are to be constructed of three-quarter (¾) inch channels, set vertically and spaced eighteen (18) inches centers, on which is to be wired No. 20 expanded metal lath; and the two surfaces are then to be plastered with two coats each of hard wall-plaster. The interior of outside walls and the ceiling are to be finished in the same manner as the partitions. The rooms are to be ventilated by registers in the ceiling, and openings are to be left in the walls of the stairway mantel to conduct the air from the space between the ceiling and the roof and from the open court to the top of the mantel, all as shown on the drawings. Doors and windows are to be provided in the house, as shown in the plans.

Around the edge of the roof an eight (8) inch gutter of cast iron is to be placed. This gutter is to be three-eighths (⅜) of an inch thick, and is to be cast in lengths of about ten (10) feet. It will be supported at the corners and at the center of each side with brackets constructed of two (2) inch by three-eighths (⅜) inch flat steel bars. Bell joints are to be provided, and they are to be thoroughly caulked with lead. The gutter is to have a slope of one (1) inch in twenty (20) feet. Two (2) conductors of six (6) inch wrought iron pipe are to be provided with the necessary elbows and other fittings to carry the water from the gutter to the cast iron tank in the yard. The pipe is to have a flange resting on the cover of tank and is to extend six (6) inches into same.

Concrete steps are to be provided at the two entrances of the building.

Holes are to be provided in the roof for the stove-pipe ventilators mentioned under "Hardware."

For details of dwelling see Sheet No. 5.

WOOD WORK.

The wood work for these buildings will consist of the windows and doors, their frames and casings, and the closets and cupboards. All wood work will be of clear white pine, thoroughly seasoned, free from all shakes, sap and other defects. All workmanship is to be first-class. All doors and sash are to be one and three-fourths (1¾) inches thick, and are to have rain channels plowed as shown on drawings. Casement windows and double doors are to have moulded oak joint-strips inside and out.

All outside doors leading to the central court of dwelling, doors in stairway and watch-room, and the two doors from office to bedrooms, are to have upper panels of glass, as called for on drawings All doors and sash are to be neatly moulded and well pinned and glued.

All junctions of plaster and wood work will be covered by one and one-quarter by one and three-quarter (1¼ x 1¾) inch moulding. This moulding will form the casing of all doors and windows. A closet is to be provided in one corner of each bed room, two (2) of them in the office, and a cupboard in each kitchen.

The cupboards are to be eight (8) feet six (6) inches in height, and are to be divided into two (2) compartments. The lower compartments are to be three (3) feet six (6) inches high, and are to have only a bottom shelf, each upper compartment having four shelves besides the division shelves.

Drain boards two (2) feet long are to be provided for each sink.

The lower compartments of closets are to be two (2) feet six (6) inches high, and they are each to have three (3) shelves; the upper compartments are to have only one shelf at top. For details see Sheet No. 5.

All wood work is to be surfaced, sand-papered and primed on both sides before leaving the shop. It must be kept dry and must be securely boxed for shipment.

All wood work is to be treated by some process, to be approved by the Engineer, so as to render it non-combustible.

The following are some characteristic specific clauses from our "Specifications for a Steel Pier to be built in the Harbor of Vera Cruz, Mexico, for the Vera Cruz and Pacific Railway Company."

GENERAL DESCRIPTION.

The structure will consist of a platform of creosoted timber, four hundred and ninety-two (492) feet long by seventy-four (74) feet wide, resting on steel joists, spaced about four and one-half (4½) feet centers, which in turn rest on double I-beam girders that are supported at intervals of fourteen (14) feet six (6) inches by screw piles.

These piles are thoroughly braced so as to form independent towers with four (4) piles to each tower, the bracing extending from the top down to, and in some cases even into, the sand.

At the middle of the platform and extending over its entire length is a double-track railway, the rails for same resting on and spiking to the six (6) inch timber floor, of which the platform is composed. Between the rails is laid four (4) inch planking, and beyond the outer rails are beveled planks, all to facilitate the passage of trucks and vehicles over the rails.

Around the entire periphery of the two sides and the outer end of the pier runs a twelve (12) inch by twelve (12) inch timber fender, bolted firmly to the metal work; and on each side of the pier there are located at intervals five (5) cast iron mooring posts.

Each railway track is supported by four (4) runs of steel I-beams, braced together in pairs by diaphragms of steel channels.

The deck is swayed in a horizontal plane by adjustable diagonal rods that attach by clevises to the cast iron caps over the piles.

The tower bracing consists of horizontal struts, each composed of two (2) six (6) inch by four (4) inch T's and diagonal rods adjusted by turnbuckles. The bracing is connected to the piles by forged steel clamps.

The piles, which are of seven (7) inch solid cylinders, are to be preferably in one length; but splices will be permitted, and, in fact, are provided for on the drawings.

The screws are to be of cast iron, four (4) feet nine (9) inches in diameter, and are to have sockets for receiving the ends of the steel piles. The shoes are held in place by means of steel pins passing through both the pile and the shoe.

The cross girders are to be bolted to the pile caps; the joists are to be riveted to the cross girders; the flooring is to be attached to the joists by lag screws and beveled washers, and the planking at railroad tracks is to be spiked to the flooring by eight (8) inch by one-half (½) inch square spikes, two (2) spikes being used for each running foot of plank.

MODUS OPERANDI OF CONSTRUCTION.

All piles are to be placed in as nearly exact position as it is practicable to get them. As no adjustment has been provided for in the bracing struts, the four (4) piles forming a tower must be sunk within an eighth (⅛) of an inch of true position. In order to secure such an accurate location with reference to each other, some form of portable, convenient and rigid template must be used to set and hold the four (4) piles of each tower to exact position during sinking. The Contractor, before proceeding with the work, shall submit to the Engineer for approval a complete description and plans, explaining fully the method he proposes to adopt.

The power applied for screwing the piles in place shall not be great enough to strain them in torsion beyond the elastic limit of the material.

Great care must be exercised to get the piles down to exact elevation.

All bracing must be put in under water by divers. All clamps must grip the piles so tightly that they will develop the full strength of the diagonal rods attaching to them, without slipping. All diagonal rods must be tightened and adjusted to the satisfaction of the Engineer.

After the bracing is adjusted all towers must stand plumb, and the plan of each tower must be a perfect square.

Before the timber floor is put on the upper lateral diagonals must be carefully adjusted, so as to bring the platform to perfect alignment.

All sand and silt that would interfere with the placing of the bracing as shown on the plans must be removed; and there will be no direct payment for this removal, as its cost must be covered by the pound price bid for the erected metal.

BORINGS.

Very thorough borings have been made by the Company's engineers and the results thereof are shown on Sheet No. 1 of the accompanying plans. Although the said borings indicate that no unusual difficulty will be encountered in sinking the piles because of obstacles in the sand, it is possible that such obstacles do exist, and the Contractor must take the risk of encountering them, as there will be no extra compensation allowed therefor.

PILES.

All piles shall be sunk to exact position by means of adequate machinery, power, and guide frames, all of which, before being used, must be approved by the Engineer. Such approval, though, shall not be interpreted as giving the Contractor any claim whatsoever for avoidance of responsibility in respect to correctness of final position of piles.

All piles are to be screwed down to the elevations shown on Sheet No. 1, but if there be any slight inequality in elevations of tops of piles, the same shall be adjusted by means of thin, cylindrical shimming plates, seven (7) inches in diameter, to be placed between the heads of the piles and the cast iron caps. Should any pile be left too high, its top shall be sawed off to exact level; but, as this would be expensive, the Contractor should endeavor to sink all piles a trifle low, so as to shim upon each a small amount. He should also provide an ample number of shimming plates of various thicknesses. The greatest variation of height of column to be taken up by shimming plates shall in no case exceed one and one-half (1½) inches.

No variation in elevation of tops of pile castings exceeding one-sixteenth ($\frac{1}{16}$) of an inch will be permitted. The spaces between the pile heads and sockets of castings shall be filled completely with hot, thick asphaltum, by putting an excess thereof in the casting just as the latter is about to be placed, and the said asphaltum must be held permanently in the annular space by caulking tightly with sheet lead from below.

This work must all be done to the satisfaction and acceptance of the Engineer, and there will be no direct payment made for either lead, asphaltum, or labor involved in putting these in place, as the pound price for the metal-work must cover the cost of these materials and labor.

PAINTING.

All metal-work before leaving the shop shall be thoroughly cleansed from all loose scale, rust, and dirt, and shall then be given one coat of paint, which coat shall be thoroughly dried before the metal-work is loaded for shipment. It is absolutely essential that the entire surface of the metal-work be thoroughly cleansed by the most effective known methods, such as the use of wire-brushes, then the painter's torch, and in certain cases the application of a strong caustic solution, followed by scraping, washing with clean water and drying.

In riveted work all surfaces coming in contact shall be extra well painted before being riveted together. Bottoms of bed-plates, bearing-plates, and any other parts which are not accessible for painting after erection shall have three (3) coats of paint, one at the shop, and the other two in the field before erection. Pins, bored pin-holes, and all other polished surfaces shall be coated with white lead and tallow before shipment from the shop.

Oil should be used as the lubricant for reaming, but, should soapsuds be employed, all parts of the metal affected thereby must be washed thoroughly and dried before any painting is done thereon.

After the structure is erected, the metal-work shall be thoroughly cleansed from mud, grease, or any other objectionable material that may be found thereon, then thoroughly and evenly painted with two (2) coats of paint.

The paint to be used on the metal-work is known as Leiter's Air-Drying Paint, sold by the L. Z. Leiter Co., 81 South Clark Street, Chicago, Ill., and costing there one dollar and twenty-five cents ($1.25) per gallon. The Engineer reserves the right to substitute any other paint which in his opinion is equally good or better for resisting the corrosive effects of salt water.

All three coats of paint given to the metal-work are to be of distinctly different shades or colors, and the second coat must be allowed to dry thoroughly before the third coat is applied.

No thinning of paint with turpentine, benzine or other thinner will be allowed without special written permission from the Engineer.

No painting is to be done in wet weather.

All painting is to be done in a thorough and workmanlike manner, to the satisfaction of the Engineer, and no paint whatever is to be used on the structure without first being approved by the Engineer.

All materials for painting shall be subject at all times to the closest inspection and chemical analysis, and the detection of any inferior quality of such material, in either shop or field, shall involve the rejection of all suspected material at hand and the scraping and repainting of those portions of the work that, in the opinion of the Engineer, were defectively painted on account of such inferior material.

All recesses that would retain water or through which water could enter must be filled with thick paint or some water-proof cement before receiving final painting. All surfaces so close together as to prevent the insertion of paint-brushes must be painted thoroughly by using a piece of cloth instead of the brush.

LOADING METAL-WORK ON VESSEL AND PREPARING SAME THEREFOR.

Pains must be taken to mark clearly every piece, bundle or package with the shipping address and destination, with the names and numbers of pieces, and with any other such mark of identification as may be necessary to insure the correct disposition of the material.

All small parts, such as rivets, bolts, nuts, washers, pins, fillers, small connection plates, etc., shall be boxed strongly, and the contents shall be marked plainly on each box, in addition to the shipping address mentioned above.

All lateral angles shall be bolted together in pairs; and as many of such pairs shall be bundled together with clamps or wire as will be convenient for handling without injury in loading and unloading.

All pieces with open ends, such as truss-members with forked ends, or laterals with unsupported plates or angles, or any other parts liable to injury in handling, shall have the ends packed with heavy blocks of timber, bolted thoroughly between the projections or to the body of the member in such a manner as to prevent any bending or other injury in handling or on shipboard.

All nuts on any rods or bolts shipped loose shall be screwed tightly in place, and the threads thereof shall be wound closely with twine so that the nuts cannot come loose and be lost off in handling.

The shipping invoices or lists are to be made to correspond to the bundles, boxes and packages, so that each item on the list can be identified readily.

During both the loading on steamer and the unloading from same, special care shall be taken to avoid injuring any of the metal-work, and the loading shall be so done as not to overstrain unduly any part and so as to prevent any shifting during the voyage. If, in spite of all precautions, some of the metal-work be injured, the entire expense to which the Company is put because of such injury shall be borne by the Contractor.

All the expense involved by these special shipping and loading directions shall be borne by the Contractor, as no extra payment will be allowed therefor.

I desire to call your attention to the importance of including in specifications for metalwork that is to be transported by water full instructions for loading the material in such a manner as to reduce to a minimum the danger of injury in transit. Unless this matter receives due consideration in the specifications, and unless the latter be strictly lived up to in this particular, the metal is liable to be so damaged during transportation as to necessitate the rejection and replacement of some important parts, thus involving for the construction long and often serious delays.

The following characteristic clauses are taken from our "Specifications for Steel Pipe Line for the City of Kansas City, Mo."

GENERAL DESCRIPTION.

The work is to consist of a buried pipe line, covered to a depth of at least three (3) feet above the top thereof.

The pipe shall be forty-eight (48) inches internal diameter (irrespective of the rivet heads), and shall be made of soft steel one-half (½) inch thick.

Bidders, however, shall tender also on a pipe of thirty-six (36) inches minimum internal diameter (irrespective of the rivet heads), made of soft steel three-eighths (⅜) of an inch thick.

All joints are to be lap joints, the longitudinal ones being double riveted, and the transverse ones single-riveted.

The length of the over-lap for the longitudinal joints shall be five and one-half (5½) inches, and that for the transverse joints three (3) inches.

There shall be but one longitudinal joint in any section of pipe.

All rivets are to be of soft steel, three-quarters (¾) of an inch in diameter and spaced two and one-half (2½) inches centers, as shown on the accompanying drawings.

The pipe is to be built in sections telescoping into each other, each secbeing seven (7) feet long, and there being four (4) sections riveted together in the shops, thus making the length of pipe for shipment twenty-seven (27) feet three (3) inches from out to out, four (4) of such forty-eight (48) inch pipes making a carload.

The distance from center line of rivets to edge of plate is to be one and one-half (1½) inches.

The larger sections shall be of such internal diameter that the smaller sections will fit tightly inside them after the lap joints have been drawn out to thin edges.

All joints are to be caulked so as to be absolutely water tight under a three hundred (300) foot head.

The longitudinal joints are to be so located that, when the pipe is laid, they shall lie on top thereof alternately to right and left of the vertical axial plane, and so that the nearer row of longitudinal rivets shall be six (6) inches therefrom.

All pipe shall be formed to correct cylindrical shape, and any lengths discovered to be out of true will be rejected.

Where the pipe passes beneath any railroad track it shall be stiffened as follows:

Six (6) longitudinal angle-irons 3 inches x 3 inches x ½ inch shall be spaced, as nearly as may, equidistant around the periphery of the pipe and riveted thereto, fillers being placed beneath them to afford a flush bearing. These angle-irons are to be twenty-seven (27) feet long, as they must run without splicing the full length of the four (4) continuous seven-foot sections.

At the middle of each seven-foot section there is to be a ring of 3-inch x 3-inch x ½-inch angles in six (6) pieces (so as to lie between the longitudinal stiffeners) riveted to the pipe.

Finally, there is to be a single 6-inch x 3½-inch x ½-inch angle-iron bent to a true circle with the long leg vertical, the said leg riveting to the vertical legs of the previously mentioned ring angles.

It will be necessary to notch the six-inch leg so as to straddle the radial legs of the longitudinal stiffeners.

The joint in this outer ring is to be placed opposite the middle of one of the six pieces of circular angle iron, and the said joint is to be spliced with a piece of plate, ten (10) inches wide, bent to fit outside of the 6-inch x 3½-inch angle.

The details of this stiffening are shown clearly on one of the accompanying drawings.

Where two of these stiffened pipes come together in the field, each opposing pair of longitudinal stiffeners is to be spliced by attaching to the vertical leg thereof a piece of 3-inch x 3-inch x ½-inch angle, two (2) feet long, riveted through one leg to the stiffeners and through the other to the pipe, there being four (4) rivets to each leg on each side of the joint.

FORMATION OF ANGLES AND CURVES.

Where angles or curves occur in the alignment or grade of the pipe line, the plates are to be cut and punched to the required bevel so as to produce an oblique angle at the circular seams, carrying this style of construction over a sufficient length of pipe to secure the total deflection required. It may in some cases be necessary to enlarge slightly the exterior lengths of pipe; but extra care will have to be taken to caulk all such oblique joints.

PROTECTION OF METAL.

The pipe shall be dipped vertically in a bath of Assyrian Asphalt, Smith's Durable Metal Coating, Mineral Rubber Coating, or some other paint which, in the opinion of the Engineer, is equally as good as any of those just named.

The coating shall be heated to a temperature of four hundred (400) degrees F. or more, and all pipes shall receive a uniform coating of not less than one thirty-second ($\frac{1}{32}$) of an inch in thickness.

After the sections have been removed from the dipping tank, they shall be set vertically to dry. All joints shall receive three (3) coats of paint before they are riveted up. All spots on which the coating has been injured in handling must be thoroughly recoated.

The particular kind of coating to be used will be decided later by the Engineer.

And now, although I have read many of these specific clauses simply by title, intending to let you study them thoroughly later on if you so desire, it appears to me that you have had about enough of this ultra-technical discourse, and that, if I don't cease talking pretty soon, you will be tempted to nickname me "Dr. Dryasdust"; consequently I shall say no more about specifications, except that I advise everyone of you to make a special study of the subject; first, by collecting and perusing carefully a number of truly first-class specifications written by engineers of wide experience; and, second, by attempting to write for yourselves specifications for various types of engineering construction. Remember that you cannot hope to learn to write even approximately complete and correct specifications until after you have had many years of practical experience in engineering work; therefore do not be discouraged if at first you find the task too great for your unavoidably limited experience.

In concluding this series of lectures, I beg to thank you, young gentlemen, for the attention and courtesy you have shown me and for the appreciation of my efforts that you have manifested.

COMMENT.

The spirit or intent of the engineer who drew them is the essence of specifications, and a court of law will decide a dispute in accord with it, consequently, it should stand out clearly and be quite evident upon a casual reading. It will exert a material influence upon the contractor's bid and upon his attitude in relation to the small points which always remain uncovered in even the most carefully drawn specifications.

Every clause should have a direct bearing upon the work to be done, and every material point pertaining to the work or to the business relations which govern it should receive proportionate attention. Omissions may be covered by a blanket clause which places the entire matter under the control of the engineer, but this method is slipshod; invites disputes, delays, and additional expense; and demands more constant supervision. It keeps the contractor and his foremen uneasy, because they are never certain that the work is being done strictly in accord with the engineer's desires. If the engineer or his representative is not constantly present, the work must be delayed until a decision is obtained. This is a source of irritation and expense to the contractor and must always be paid for in the end by the engineer's principal. A very full and complete specification requires time and careful labor for its preparation, but it produces results most satisfactory to all parties and insures low tenders.

The clauses which relate to tests and inspection merit especial care. The number and character of the tests and their bearing upon the acceptance of the material, the time for making the tests and for notifying the engineer when the material is ready for inspection, and the penalty for neglect to comply with these requirements should be set forth in detail, since indefiniteness in these matters is a source of much friction.

Specifications for materials should invariably be based upon definite and accurate knowledge of their properties. If the materials demanded are not to be obtained in the open market at a reasonable price, the value of the construction will not be in proportion to its cost. Again, improvements in manufacture succeed each other very rapidly, and it is essential that the progressive engineer keep well informed regarding the properties and values of new and improved materials; otherwise, he may specify the more expensive of two equally good and available ones, to the detriment of his client. If, upon full investigation, the engineer is satisfied that the newly developed material is unreliable, or otherwise unsuited for his purpose, he should undoubtedly act upon his opinion and refuse to use it, even though it is generally accepted by men who are competent judges. It should be his business to know why he chooses the more expensive material, and to be sure that he is not ruled by prejudice. One prominent engineer continued to specify wrought iron for bridges long after steel had superseded it, and when it could only be obtained at a cost much greater than that of the superior metal. Another continued to use acid open-hearth steel long after the cheaper metal made by the basic process had been so universally accepted that the most prominent manufacturer in the country had ceased to use the acid process. The honesty of these engineers is not to be questioned. Can as much be said of their judgment? In another instance an engineer made himself ridiculous by accepting hearsay evidence and specifying a metal of a grade so high that it has never been produced.

In preparing plans and specifications, the prices at which materials can be obtained or delivered on the site of the work are quite as important as their physical and chemical properties. It is the duty of the engineer to obtain the most satisfactory structure, and to obtain it at the lowest cost consistent with the best quality and design. Not since the day of the despots who built the pyramids and similar structures with slave labor has the cost failed to be an important factor in the construction of engineering works. Where large quantities of materials are to be used, very careful consideration must be given to those most readily obtainable and most economical for the particular construction in question. Guess work is not good enough, as it is always possible to obtain satisfactory information regarding prices in a very short time.

It is always important to specify units of measurement as well as units of price. Specifications often fail to state whether excavation shall be measured in the cut or in the embankment, and to make clear distinctions between the varieties of material to be excavated. Specifications for concrete state the proportions of cement, sand, and broken stone or gravel to be used, but frequently neglect to specify whether the unit of measurement is weight or bulk, and whether the cement is to be measured loose or as it comes in the package.

It is a good plan to place on the drawings a brief specification covering the most essential points, also those that are unusual and likely to escape the contractor's attention. This duplication may lead the contractor to pay too little attention to the written specifications, but it compels the observance of the most salient features.

It is commonly advisable to reserve the right to increase or diminish the amount of construction without impairing the contract. Undue stress should not be laid upon this clause, since the probability of a decrease in the quantities will tend to increase the contractor's prices. The cost of transporting the plant and the administrative expenses do not decrease in direct proportion to the reduction in the amount of work done. If it be necessary at all to place the contractor's plant in jeopardy in order to insure proper progress on the work, as Dr. Waddell does in the specifications he quotes, it should be made impossible to take possession of his plant without ample reason and due notice. The ten days' notice is, in the editor's opinion, entirely inadequate when the contract is large, for there are many sources of delay which may be operative for more than ten days. If the contractor's rate of progress has been such that he will be able to complete the work materially within the contract time, his plant should not be subject to arbitrary seizure in case he deem it necessary to decrease his rate of work in order to give attention to other contracts. The power this clause confers might easily be used to punish the contractor for unexpected diligence, and it will certainly give him anxiety unless he knows the temper of the engineer.

Strict or even unjust clauses are by no means as detrimental to either party as those which are ambiguous. A contractor has more reason to anticipate injustice from an ignorant or over-zealous inspector who is governed by ambiguous specifications than from the most severe interpretation of very strict but definitely stated requirements, because in the latter case he knows just what to expect, while in the former his course is always uncertain.

In both the preparation and the interpretation of specifications, common sense and fair purposes are excellent guides. The engineer who is continuously unfair obtains a reputation that is detrimental both to him and to his clients, for bidders upon his work will take his characteristics into account in preparing their tenders. To cite an instance of unfair interpretations, the engineer for a large piece of difficult timber construction refused to include in his monthly estimates more than ninety per cent. of the base cost of the lumber which had been worked into place. The labor was far more expensive than the lumber, and this ruling, which withheld the due proportion of pay for it until the work was completed and accepted, caused the contractor's failure.

On the other hand, it is difficult for the engineer to safeguard his client too closely, because the nature of the contractor's business makes him sharp and, too commonly, ready to take every possible advantage. It is a wise engineer who never gives the contractor any financial advantage, for he is generally without an appreciable amount of attachable property and not easily called to account. This fact is so generally recognized that the commercial agencies rarely find a contractor in possession of sufficient property to warrant them in giving him a rating. Consequently severe, even seemingly unjust, specifications are essential. Sentiment has small part in the business relations between the engineer and his client and the contractor. Justice should rule, and the means to compel it should lie in the engineer's hands.

THE KANSAS CITY FLOW-LINE BRIDGE REPAIRS.

BY

J. A. L. WADDELL.

INTRODUCTORY NOTES.

The construction of engineering works under normal conditions, when proper materials and skilled workmen are available, and when there is sufficient time to do the work during usual working hours, requires training, energy, and both technical and executive ability, but the conditions governing the repair of the flow-line bridge at Kansas City in the summer of 1903, demanded fortitude, persistence, and courage of a high order, as well. The technical skill of the designer, the resourcefulness of the erector, the executive ability of the experienced superintendent, and the energy, the physical strength, and the courage of men accustomed to the most laborious and dangerous conditions of pioneer life, were all demanded of the engineers who carried on the work. The constant and imminent danger from fire and pestilence which threatened the city served to goad them to extreme effort, and caused them to endure fatigue and loss of sleep and to forget their own danger. There was no time to consider nice points of design, the choice of materials, and the economy of construction. The end justified the means. Every action was commendable, any delay unpardonable.

Dr. Waddell has stated very clearly the conditions under which the work was done, but it is impossible to do full justice to them in a brief description. It is difficult to imagine existence for even ten days in a modern city, suddenly deprived of light, water, transit facilities, and the use of its sewerage system. The means for a return to primitive life are not available and nothing can be substituted for the water supply. All city life, business, and industries are dependent directly or indirectly upon it. Hence, the importance of its prompt restoration in this instance cannot well be exaggerated. Neither can the value of the engineers' skill, energy, and courage be easily over-estimated.

THE KANSAS CITY FLOW-LINE BRIDGE REPAIRS.

By J. A. L. Waddell.

Because of numerous requests from engineers and others, the writer has been induced to prepare the following statement concerning the repair-work to the bridge over the Kaw River that carries the pipes for the water supply of Kansas City, one span of which structure was destroyed and the other badly injured by the great flood of May 31, 1903.

The bridge, which is located a very short distance from the river's mouth, consisted of two steel Pratt-truss spans of a rather antiquated type, the floor-beams being suspended, resting on two masonry abutments and one cylinder pier. The abutments were not used for retaining earth, as probably they were of insufficient stability. The center pier, however, was well built and consisted of two 7-ft. iron cylinders sunk to and into bed rock by the pneumatic process, well sway-braced and filled with concrete. The span that went out was 185 ft. long and the one that remained was 226 ft. The upstream truss of the latter was crippled in three vertical posts near mid-span, and in the bottom chord, and the floor beams, hangers and sway-bracing were pretty badly wrecked, rendering the span so unsafe that it was liable to fall at any time.

The accompanying photograph, No. 1, although on a very small scale, shows quite clearly the condition of the posts of the upstream truss. This picture was taken nearly a week after the bridge was wrecked and after the water had subsided several feet. During the extreme height of the flood the water came up to the cross girders, but did not quite reach the bottom chords. It was an accumulation of driftwood (a lodged portion of which appears in the photograph) that did the damage.

The shorter of the two spans was carried away about six o'clock on Sunday evening, and news of the disaster did not reach the writer, who was at Chicago, until the next day. He took the first train for home that evening, but because of numerous washouts did not arrive there until six o'clock on Wednesday morning. Mr. Ira G. Hedrick, the writer's partner, happened to be spending Sunday in Kansas City, Kansas, and saw from there this bridge and a number of the other Kaw River bridges carried down by the flood. In spite of his proximity and of his using every endeavor to reach the office, he failed to do so until a few hours after the writer's arrival, mainly because of the great currents in the Kaw and Missouri Rivers.

From the time of the disaster until the writer's arrival, Mayor Reed was making numerous endeavors to communicate with the members of the firm of Waddell & Hedrick, to whom he turned for assistance in his

FIG. 1. VIEW OF STANDING SPAN OF FLOW-LINE BRIDGE AT KANSAS CITY ONE WEEK AFTER FLOOD OF MAY 31.

hour of need. The crisis was most serious; the water supply of the city was almost entirely shut off, the small amount of water that for a short time was pumped from the Kaw River being so seriously contaminated that it was condemned by the City Chemist as absolutely poisonous. The entire city, too, was at the mercy of the fire-fiends, and had it not been for the numerous and thorough precautions taken by Mayor Reed and his officers, Kansas City would have been given over to the flames. Again, owing to the failure of the water supply, the street cars stopped running, the sewers fouled for want of flushing, the general use of water-closets throughout the city had to be abandoned, the gas supply for a time was stopped, and the electric light plant was placed *hors de combat.*

The entire city was truly in a bad plight, threatened as it was with fire, pestilence, robbery and drought; so there was no time to lose. All depended upon the quick repairing of the broken pipe line and the replacing of its supporting bridge.

At ten a. m. on June 3 the writer met the Mayor and received from him instructions to prepare a plan to build, regardless of expense and in the shortest possible time, some kind of a structure which would carry safely the pipe and its load of water, and thus relieve the dire need of the city.

Upon consultation with Mr. W. G. Goodwin, Superintendent of the Water Works, the writer found that he and his assistants were debating whether it would be better to build a pontoon or a suspension bridge, a pile structure being deemed out of the question. The writer decided at once against a pontoon bridge because of the danger from drift and the trouble which would be encountered from rising and falling water, and pronounced in favor of a suspension bridge.

During the forenoon arrangements were made for the use of a large steamer for the purpose of visiting the wreck and determining the conditions; so shortly after noon Mr. Hedrick, Mr. Robert W. Waddell (ex-City Engineer), the writer, and a number of others made the trip.

Although the water had fallen considerably, it was still almost up to the floor of the remaining span, and the current was so swift that the steamer was unable to make any headway against it. It might have been practicable to reach the structure by floating down against it in a small boat, but the risk involved would have been great, so it was not attempted. Moreover, barring the actual condition of the remaining span, all the information required for rebuilding the bridge upon the suspension span basis was collected.

One anchorage was located upon the high ground in the street on the west bank and the other adjacent to a railroad embankment which formed the approach to what had been the Chicago Great Western bridge. As the river was almost at the level of the top of this bank, it was necessary to construct the anchorage in the water, running the back-stays through the embankment close to the rails. These back-stays were to be carried from the center pier along the top chords of the remaining span, being supported over the pier and east abutment by timber bents. One of these was required also over the west abutment.

By carrying the cables along the top chords and by making the timber bents of the same height as its trusses, the crippled span was not called upon to sustain any stress from the suspension span (as had at first been contemplated by the Water Works officials), excepting only that it would have to support a small portion of the weight of the cables lying thereon. In view of the dangerous appearance of the span this was deemed a necessity.

We returned to the office about four o'clock and immediately the designing was started, while the telephone was utilized in searching for materials. At this time Kansas City was practically cut off from the outside world as far as freight transportation was concerned; consequently it was necessary for us to procure all the materials for the bridge from local dealers. Already for two or three days there had been a large demand for timber to be used in various kinds of repair work, and we were, therefore, unable to procure the large timbers we needed and were forced to figure on building many of them out of planks.

For main cables we were compelled to adopt some second-hand, one-and-a-half inch diameter wire ropes belonging to the Metropolitan Street Railway Company. These had been used by their cable railways as long as it was deemed safe to employ them and then stored away as refuse. It was figured that they still retained one-half of their original strength, or 50,000 lbs., and we aimed to strain them about one-third of that amount.

As for suspenders, we found a supply of new one-half inch wire rope said to have an ultimate strength of four tons. This we decided to use with a factor of safety of about four. Unfortunately, as we learned later on, a mistake had been made concerning the strength of this rope, which mistake nearly involved us in serious trouble.

For other metal the Riverside Iron Works Company kindly put their stock and shops at our disposal.

An ample supply of Portland cement was obtainable, although great quantities of it had been ruined by the flood, most of the cement houses being located on the river bottoms.

A supply of good sand was found close to the east end of the bridge, having been stored there by one of the railroad companies. This became available as the water level fell.

Broken stone could be obtained in the city and barged to the site with the aid of steamers.

Plant and tools were to be had from the local office of the American Bridge Co., and these were generously placed at our disposal.

Plenty of bridgemen and laborers were at hand, owing to the cessation of work caused by the floods.

We labored steadily on the computations and drawings until darkness overtook us; then we endeavored to turn on the electric light, but found that it was cut off because of the want of water to supply the boilers. The use of kerosene had been declared illegal, and what was more to the point, we had no lamps. At this hour all the stores were closed, hence we were forced to beg candles from the Midland Hotel and to improvise candlesticks. With this insufficient light, by working until after midnight, we succeeded in finishing the pencil drawings and bills of materials.

Early next morning (June 4) our report to the Mayor was handed in; but as it had to be acted upon by the City Council, it was not until nearly four o'clock that we were empowered to go ahead. By six o'clock all the materials were ordered, and some of them were started by wagon to the temporary steamboat landing at the foot of the Fourth Street Viaduct; barges and boats were secured for transportation, and workmen were ordered to report early next morning at the site.

The services of Mr. George H. Griffin, lately foreman for the American Bridge Co., were secured, and it was arranged that he was to provide and take charge of all the skilled laborers.

Early the next morning (June 5), under the direct supervision of Mr. Hedrick, work on the west anchorage was begun. By seven o'clock wagons containing timber, cement and broken stone were lined up at the landing waiting for the barges. As soon as these appeared they were loaded, and the materials were transported to the site of the east anchorage, where a small amount of dry land on top of the embankment had begun to show itself above the water. On this the materials were stored, and by noon the construction of the coffer dam was begun by Mr. Hedrick, assisted by Mr. L. R. Ash, one of our engineers.

A small pile driver was quickly constructed and a coffer dam of two rows of sheet-piling with clay between was built, concreting therein being started about midnight of the same day, as the pile driving was finished at nine o'clock.

By working continuously the entire anchorage was completed at one o'clock of Saturday afternoon, June 6. Both Mr. Hedrick and Mr. Ash stayed on this work without rest from start to finish.

Meanwhile the construction of the west anchorage was being continued under the direction of Mr. V. H. Cochrane, our chief draftsman, and Mr. C. K. Allen, a former employee of our firm, but at that time in the employ of the City Water Works, his services having been lent us on this special occasion. This west anchorage was completed at 7 a. m. of Saturday, June 6.

Before proceeding further with the history of the construction, it will be well to describe the structure that was building.

The new span consisted of eight (8) of the second-hand steel cables, four (4) per side, having a deflection of about twenty-four (24) feet. These rested on the timber bents over the center pier and west abutment, which bents have already been mentioned. Each bent consisted of five (5) 12″ x 12″ verts., a 12″ x 12″ cap, and a 12″ x 12″ sill, sway-braced on both sides with 4″ x 12″ planks. On top of the cap near each end was placed a saddle formed of a rounded 12″ x 12″ timber covered with a one-half inch steel plate. The suspended span is divided into twenty panels of nine feet three inches (9′ 3″) each, the suspender cables being wrapped around the main cables and having their ends secured by three standard clamps each.

These suspenders attach at their lower ends by thimbles to beam hangers that run at a slight angle to the vertical through the floor beams, each of which is a single 8″ x 8″ x 16′ yellow pine timber. On top of the beams run longitudinal floor planks, and these are swayed beneath by crossed planks spiked thereto.

The stiffening trusses, which are spaced nine feet six inches (9′ 6″) from center to center, are six (6) feet deep between centers of chords. They are built entirely of 2″ x 12″ planks, excepting that the verts. are of 4″ x 6″ timber. The top chords are side-braced to the floor beams, it having been originally the intention to adopt pony trusses; but after the pipes were laid, as a matter of precaution and to obtain additional lateral rigidity, an overhead system of horizontal sway bracing was added. The pipes rest on shims of 8″ x 8″ timber placed directly over the floor beams.

The accompanying drawings, copied from our hastily prepared and rather crude working drawings, illustrate the features of the bridge which have just been described. It is to be noted, however, that the plan shows an additional pipe carried by the structure and the strengthening of the latter for same; of which more anon.

The accompanying photograph, No. 2, shows the finished bridge, and illustrates quite clearly most of the features and details mentioned.

As can be seen on the drawings, the main cables pass around a six inch (6″) car axle that rests against four 12″ x 12″ timbers, all embedded in the concrete, and are then carried outside of the anchorage, where they are connected by standard clips.

The timber bents over the pier and the east abutment are stayed to the portals of the old span by timbers well bolted at each end. This bracing gave us a little trouble when adjusting the cables, but it was overcome without much difficulty.

The material for the bents was framed on Friday night and Saturday forenoon. It was necessary to build most of the large 12″ x 12″ timbers

FIG. 2. SUSPENSION SPAN OF FLOW-LINE BRIDGE.

FIG. 3. VIEW SHOWING TIMBER BENTS ERECTED FOR FLOW-LINE SUSPENSION SPAN. (SPAN OF JAMES ST. BRIDGE IN THE BACKGROUND.)

of 2" x 12" planks, well spiked together. The timbers for the stiffening trusses were framed on Saturday during the night.

By Sunday morning the bents were erected, and during that day the cables were unloaded and inserted into the west anchorage. By sundown one cable had been carried across, and during the night three more cables were put in place. One of them, unfortunately, had been cut too short, so it was necessary to splice it. To do this, we sent a man out in a tub with a lantern. His position appeared precarious in the extreme, suspended as he was in the darkness over the raging flood; but he managed to make the splice without coming to grief.

This was not the only piece of bad luck that we had that night, for about nine o'clock the remaining span of the James Street Bridge, which was situated a short distance up stream from our work, went out with a loud crash and a roar of water, frightening the workmen to such an extent as to cause a stampede for the shore. In truth there was some danger to our bridge, as the floating floor system came perilously close to the deck of the old span, but luckily it passed without lodging. It was some time, however, before the men got over their fright and could be induced to resume work.

The accompanying photograph, No. 3, shows the span that went out. It was taken only a few hours before the final accident occurred. This was caused by the undermining and partial wrecking (during the flood) of the east abutment on which it rested. The proximity of this span to our work is shown clearly in the picture.

On Monday forenoon the remaining main cables were strung, and before midnight they were all adjusted to practically the same tension.

Up to this time Mr. Hedrick had been working day and night almost without any sleep, lying down occasionally on the soft side of a plank for forty winks, while the writer had been engaged mainly in forwarding materials, procuring food for the workmen, and incidentally attending to office correspondence. For this night it was arranged that Mr. Hedrick should leave the work early so as to obtain a full night's sleep, and that the writer should take charge about ten o'clock, one of our assistants looking after the work meanwhile. As luck would have it, the man running the naphtha launch, which was to have met the writer at the landing, failed to put in an appearance; therefore, after waiting an hour for him, and there being no other way to reach the bridge, the writer requested the captain of our steamer to take him there. This steamer was then on its way to pull off another steamer stranded near the mouth of the Kaw, a job that was expected to take only a few minutes. The result of the attempt, though, was to place our steamer in the same predicament; consequently the writer was forced to spend the night out on the river and was not able to get away until daylight, when he hailed a small boat that was passing.

During the previous day a large force of men had been at work on the old span, putting in temporary wooden stringers and repairing the floor so as to make it strong enough to carry the pipes and their load of water; but nothing had been done as yet to strengthen the crippled upstream truss. We recognized that there was danger involved by this omission, but there were so many other things to be done all at once that we took the chance, keeping an eye on the bent posts so as to make sure that they buckled no further.

This floor repair work was continued after dark by means of the torches with which, from the outset, the work had been liberally supplied. About one o'clock in the morning the foreman in charge made up his mind that the injured posts were failing; so he called his men off the bridge, and in consequence no work was done during the remaining hours of darkness.

Upon the writer's arrival soon after daybreak he interviewed the men and found that they were all afraid to go again upon the crippled span. By offering double pay until it was strengthened and by pointing out that the engineers would remain upon it until the posts were reinforced, a few of the men were induced to resume work, but many of them held off until after the wooden posts were in place.

The first thing to do was to relieve the largest and most injured of the three bent verts. by placing alongside two timbers bearing at top on a timber shim inserted beneath the upper chord and at bottom on a similar shim resting on the chord bars. What the bending effect induced on the latter amounted to we did not stop to figure, for our judgment satisfied us that the bars would stand the extra strain, notwithstanding the fact that they were already bent considerably out of line.

During the day both the top and bottom chords were stayed by guy-ropes to the old water works building, because the bottom chords had been bowed out of line by the drift, and the men were afraid that the span would fail by increased buckling. In the opinion of the engineers, this staying was not necessary; but they did it to pacify the men and to induce them to resume work.

By sundown a working platform had been constructed and suspended from the cables at the west bent by means of ropes and pulleys. The small suspender cables, with all the necessary tools for fastening them on, were placed upon this platform, and then four workmen and an engineer got aboard and were pulled across the river from the other side, fastening the suspenders at the proper intervals as they went along. This task occupied the entire night, and at midnight a lunch was sent out to the men by means of a keg fastened to a rope "ferry" stretched across the opening.

As quickly as the suspender cables were fastened on, the cross beams were hung at their lower ends, and early in the morning (Wednesday, June 10) planks were laid on the beams so that the workmen could walk over.

Work on the stiffening trusses was begun on the same afternoon under Messrs. Ash and Allen, operating from both ends and meeting at mid-span during the night.

Thursday and Thursday night were occupied in finishing the stiffening trusses; laying flooring and shims for the pipes and adjusting the height of the floor.

In respect to the latter a change was made in the plans against the advice of the engineers; for Superintendent Goodwin, seeing that we had left in a camber of four feet, insisted on Mr. Ash (who was in charge at the time) lowering the beams two feet at mid-span, asserting that, unless this were done, it would be impossible for him to connect his pipe. Mr. Ash told Mr. Goodwin that in our opinion the weight of the pipes and their contents would be sufficient to take out nearly all of the four-foot camber. Nothing would satisfy him, though, but lowering the floor, so that was done, the result being, as shown in the accompanying photographs, a reverse camber of about eighteen inches. This really does no harm, but it looks ugly. Of course it is practicable to take up the sag by means of the adjustments in the main cables.

These adjustments, by the way, are of sufficient interest to warrant a description. The device, which was evolved by Mr. Hedrick, consists of a pair of heavy fifteen (15) inch channels placed back to back, with a space of three (3) inches between, through which pass short screw bolts having a nut at one end and an eye at the other for the attachment of the cable. These bolts act alternately in opposite directions, as shown on the accompanying sketch. This detail is both simple and effective.

While the suspender cables were being attached, their great pliability caused us to think that they had not the strength we were counting upon, and this opinion was corroborated by the breaking of a piece of cable used on the work. By investigation we found that the dealer who supplied the cable had made a mistake in obtaining its strength from his tables, and had furnished us with rope of only one-half the capacity we had figured upon. In consequence of this discovery we arranged immediately to reinforce the suspenders; and, as we had experienced much difficulty in distributing the loading equally on them, as a matter of precaution, we decided, since we had an ample supply of the rope, to triple instead of double the suspenders.

Pipe laying was begun about 3 p. m. on Thursday, and early Friday morning the pipes were all laid and connected, although the supporting shims were not all in and a number of the suspenders had not been strengthened.

Mr. Goodwin had been notified not to turn the water on until after we had told him all was ready, and he so instructed his assistants. However, one of them, without consulting us, on learning that the pipe was connected, telephoned to Quindaro to turn on the water. The result was that three of the weak suspenders snapped with a loud report, and the breaking of the others and consequent destruction of the entire span appeared imminent. Fortunately, the strengthened suspenders had not been put in consecutively, but were distributed with some regularity over the whole span. These upheld the load.

At the time of the accident Messrs. Ash and Cochrane were both on the west bank at some distance from the bridge. Seeing the water leaking from the partially plugged joints, Mr. Cochrane ran across the bridge to order it turned off; but found that this had already been done. By opening some valves the pipes were soon drained, and operations were resumed.

Had all the shims been in place so as to distribute the load over all the floor beams, the mishap would not have occurred, because the rope, though weak, had more than sufficient ultimate strength to carry the load when uniformly distributed.

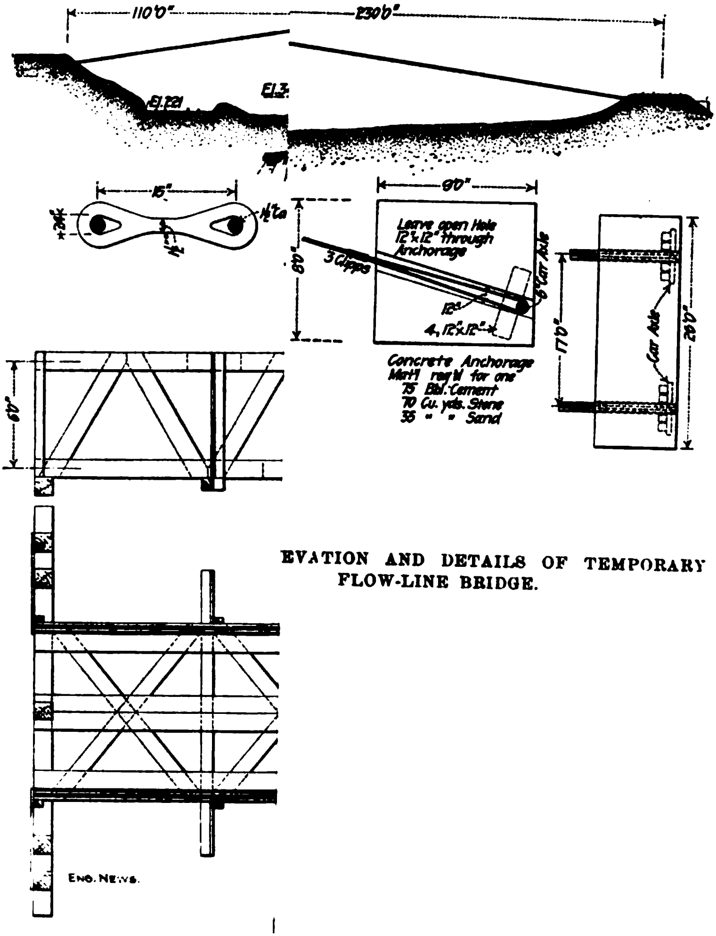
The old pipes that were used leaked like sieves, and had to be plugged with wood. They still leak somewhat, but the amount of water thus lost is inconsiderable.

It did not take long to replace the broken suspenders and to strengthen those that had not been reinforced, so by noon the water was turned on again, and the strained situation throughout the city was relieved.

From the preceding narrative it will be seen that the actual construction of the span occupied just one week, which, considering all the adverse conditions, is not a bad record.

Everything from start to finish appeared to be against us. Materials were scarce, and proper ones were often not available; the nearest telephone of any account was half a mile away from our work; means of transportation were difficult to obtain; food for the workmen was hard to get; the men operating our two naphtha launches, although under contract with the city, deserted us continually in order to earn large pay by ferrying passengers, and everybody was hustling us to get the job done and the water pipes filled.

The mental strain upon the engineers was intense, for all of us recognized that over one hundred million dollars' worth of property was in imminent danger from fire; that the health of a quarter of a million people was jeopardized by the drinking of cistern water and other impure waters and by the accumulation of filth in the unflushed sewers, and that the life of every man on the work was in constant peril.



EVATION AND DETAILS OF TEMPORARY FLOW-LINE BRIDGE.

The engineers not only did the usual engineering work, but also were compelled to perform the functions of superintendents, foremen and contractors—they even at times labored with their own hands when workmen were not present in sufficient numbers, and whenever it was necessary to give instructions how to do certain manual work.

The securing of food for the men was no sinecure, as the writer well knows, this having been one of his special duties. Arrangements for the delivery of lunches were made both by telephone and by personal interviews, but no dependence could be placed on promises to supply food, owing to the great demand therefor throughout the entire city. As an illustration of this difficulty, on Sunday, June 7, about three o'clock in the afternoon the writer learned that the lunches he had ordered for noon had not been delivered, and that the supply of coffee for the early breakfast had been entirely inadequate. The men in consequence were hungry, and were feeling the need of their accustomed stimulant. The writer immediately took a launch for the city, appropriated a city official's horse and buggy, and drove to the principal hotels and restaurants, demanding good lunches, plenty of them, and an abundance of coffee, refusing to take "No" for an answer, and telling the proprietors that, as they would be paid their own price for everything, there was no possible excuse for refusal.

In the course of an hour there were ordered in this way nearly four hundred good lunches and twenty gallons of excellent coffee, enough to keep everybody on the work satisfied until the next morning.

The next thing to be done was to get these supplies to the launch; therefore the writer attempted to secure a wagon, but everything on wheels was in service. After trying unsuccessfully four livery stables and an undertaker's establishment, and while going to still another livery stable, the writer met a one-horse wagon labelled "Water Works," stopped it, and ordered the driver to collect and carry the lunches to the landing. The fellow tried to avoid the job by claiming that he had been sent to carry some much-needed apparatus to the pumping station at Turkey Creek; consequently it was necessary to take his vehicle almost *vi et armis* and to stay with it until everything was collected and delivered to the launch.

The writer can testify from personal observation that even in the small hours of the next morning the provisions thus procured were greatly appreciated by many hungry men.

What this repair work cost no one has yet figured. In buying the materials the engineers seldom asked the price; but when they found anything they needed they ordered it sent to the site immediately, regardless of the cost of transportation.

Again, more men, twice over, were employed than would be used ordinarily on similar construction. Of course they were not handled economically; but there were usually plenty on hand whenever needed. Then, too, the night work was very expensive, not only because of the small output per man, as compared with day labor, but also on account of the higher wages paid.

Recognizing the city's dire need for the bridge, the engineers never counted cost, nor have they ever been criticised therefor, notwithstanding the appalling bills for such a small structure that the city was called upon to foot.

When the water was turned on, the engineers' work was by no means finished, for the old span had been strengthened only enough to make it safe temporarily. It was still necessary to put in one new floor beam, a number of new beam hangers, many new steel stringers, and an entirely new wooden floor, also to strengthen several injured floor beams and to repair the east portal bracing, which had been broken by the pressure from accumulated drift. This work was done more leisurely than the preceding, although no daylight hours were lost.

Soon after the water works were again in operation it was decided to lay another pipe-line over the bridge and to strengthen it for that purpose, the construction as before being placed wholly in the hands of the engineers. For this additional work we procured new main cables at St. Louis and laid them alongside the others, carrying the new pipe on additional 6" x 8" floor beams placed above the existing cross-girders, as indicated on the large-scale sectional drawing. Photograph No. 2 of the finished bridge shows clearly the additional pipe and suspenders for carrying it.

In concluding this paper the writer desires to give credit in full where credit is due.

To the great executive ability, strenuous exertions, and unfailing pluck of Mr. Ira G. Hedrick is due primarily the construction of the bridge in such a phenomenally short time and under such trying conditions. From the very start and until the water was turned on he labored day and night unceasingly, acting simultaneously as engineer, superintendent, and foreman, and continually lending a hand at hauling upon ropes or doing other manual labor.

Messrs. Ash and Cochrane deserve almost as much credit, for they, too, worked early and late up to the limit of human endurance, and seconded Mr. Hedrick most ably. Upon Mr. Ash fell a large portion of the disagreeable tasks, and he performed them most manfully. On Saturday afternoon, seeing him emerging from the coffer dam of the west anchorage, covered with mud, his good clothing ruined, haggard, and with bloodshot eyes, the writer remarked that he was the toughest looking specimen of a white man he had ever seen, and Mr. Ash could not contradict the statement.

Messrs. Allen and Hans von Unwerth attended to their share of the work faithfully and did it well.

The thanks of the entire city are due to the Stewart-Peck Sand Co., who most generously loaned us for the work several barges and one of their steamers until, as before stated, it ran aground, where it remained for a number of days.

To Mr. Robert W. Waddell, the writer's brother, and, until a short time before the flood, City Engineer of Kansas City, Mo., are due the thanks of all concerned, for, without compensation and without being solicited, he devoted several days and nights to the forwarding of materials by means of the steamer and barges belonging to his business associates, the before-mentioned Stewart-Peck Sand Co. Special mention is made of this fact, as it is the first time that any credit has been given him for his exertions.

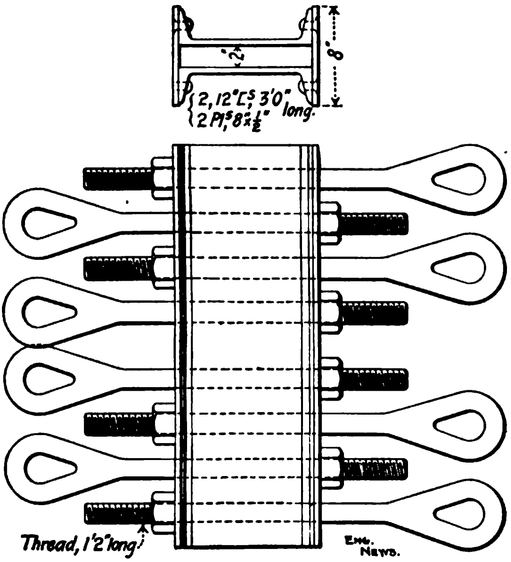


FIG. 5. DETAILS OF ADJUSTER FOR MAIN CABLES.

To Mr. George Griffin, who furnished the skilled labor and the plant, and who gave his personal attention to the job, much credit is due.

Mr. W. W. Cartter's services also must not pass unnoticed, for, notwithstanding the fact that his years number more than three-score-and-ten, he labored early and late as foreman, and never failed to stand by the work till the night, when fearing the old span was about to fall, he very properly ordered his men to leave the structure.

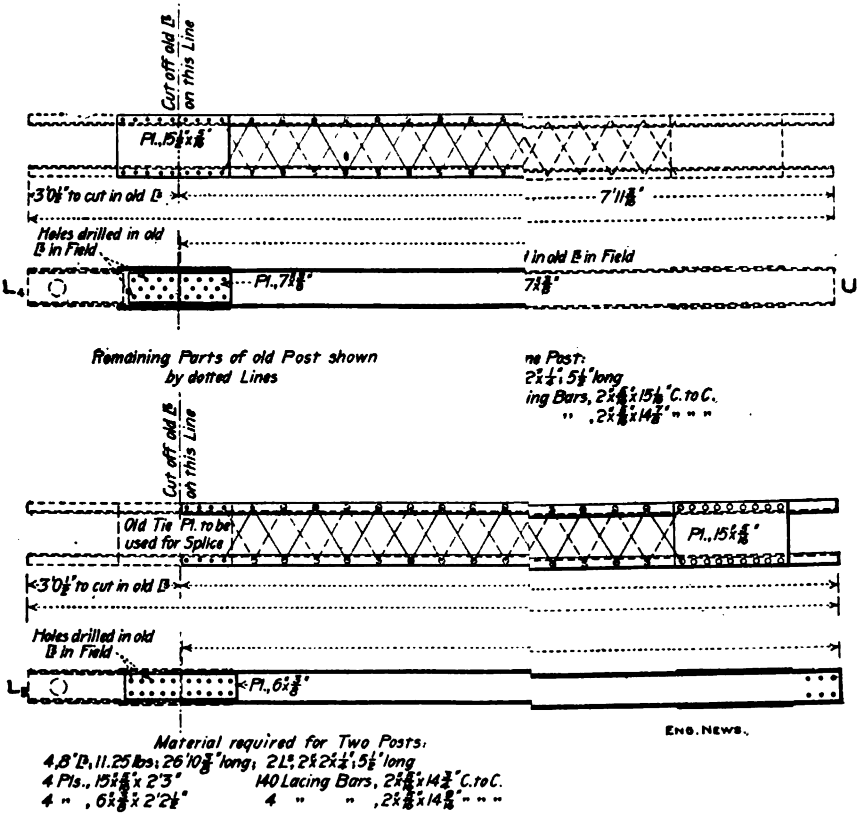
To the Riverside Iron Works the engineers' acknowledgments are due, in that they used every effort to furnish with the least possible delay all of the structural metal required for the new span and for the repairs to the old one.

And last but by no means least, every credit must be given collectively to the brave and hard-working bridgemen, by means of whose willing, intelligent and long-continued exertions the work was accomplished. Many of them labored continuously as much as thirty-six hours, and it was not merely the large compensation that influenced them, for often when a man would remark, "I am dead beat and have to quit," one of us would reply, "Brace up and tackle it again for a few hours more; it is for the good of the city, and we cannot well spare you," then he would resume work willingly and cheerfully.

Throughout the entire construction the life of every man on the structure was in danger, and, what is more, *every bridgeman on the job knew it;* but they reasoned that, if the engineers were willing to risk their lives, the workmen could do no less than follow suit. It is true that we kept at all times a short distance below the bridge a skiff with two boatmen ready to pick up any one who might fall into the river; but they could have done very little in case of the collapse of the structure.

In an article like this it would be unbecoming to mention the efforts of his Honor, Mayor Reed, and of the Superintendent of the Water Works, Mr. Goodwin, for these were the gentlemen by whom we were retained and to whom Kansas City is primarily indebted for extrication from its serious predicament; but it is perhaps permissible to state that whenever we called upon either of them to use his influence or authority on behalf of the work, it was accorded unhesitatingly and promptly.

Concerning the appearance and character of the repaired bridge no apology need be made, although it is in no sense either handsome or first class. To make it either, under the circumstances, would have been out of the question. It is doing its duty to-day satisfactorily, and all that its designers and builders now desire concerning it is that it be replaced within a reasonably short time either by a tunnel beneath the river-bed or by a scientifically designed and well built bridge.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Pl., 15½"x⅜"
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L8
Pl., 6"x⅜"
Material required for Two Posts:
4, 8" [, 11.25 lbs; 26'10⅝" long; 2 L s, 2"x2"x¼", 5½" long
4 Pls., 15"x⅜"x 2'3"
4 " , 6"x⅜"x 2'2½"
140 Lacing Bars, 2"x⅜"x14¾" C. to C.
4 " " , 2"x⅜"x14⅝" " " "
Eng. News.

FIG. 6

HIGHER EDUCATION
FOR
CIVIL ENGINEERS.

AN ADDRESS TO THE ENGINEERING SOCIETY OF
THE UNIVERSITY OF NEBRASKA.

APRIL 8, 1904.

J. A. L. WADDELL.

INTRODUCTORY NOTES.

The address on "Higher Education for Civil Engineers" was written and delivered to the Engineering Society of the University of Nebraska early in the current year, consequently, it embodies Dr. Waddell's most recent thought on the subject. It will be observed that many opinions in relation to the subjects in which a civil engineer should be educated have persisted since his first important paper on engineering education; but the idea of a graduate school of exceedingly high character is here advanced for the first time. It appears most probable to the editor that graduate work will develop easily and naturally in our present technical schools and in the universities, as the need for higher preparation develops. At first the establishment of the graduate courses only adds to the burdens of the faculty of the undergraduate school, for the students are now few who will continue their studies, not enough to warrant the institution in making large preparation for them. But, when the supply of technically trained men exceeds the demand, and competition becomes more severe, only exceptional education will assure high success, and the ablest men will devote their entire time to the graduate work. Greater facilities for original research are slowly but steadily being acquired by the better schools; and already some excellent graduate courses are offered; but exceedingly large advances must be made in the very near future.

In this day of magnificent endowments the establishment of such a school as Dr. Waddell has suggested is not impossible; witness the Carnegie Institution of Washington, which is designed to "encourage investigation, research, and discovery, show the application to the improvement of mankind, provide such buildings, laboratories, books, and apparatus as may be needed, and afford instruction of an advanced character to students properly qualified to profit thereby." The manner in which these purposes are to be accomplished is left to a board of trustees. The life and development of this country are becoming more and more dependent upon the various branches of engineering. One prominent institution, planning an especially high engineering school, employed one of our leading civil engineers to report upon the organization, equipment, methods of instruction, and character of the courses obtaining in the best technical schools of this country and Europe, and will probably establish an engineering school of the highest order in due season. In the course of time, as the bearing of engineering upon the life of the nation becomes better understood, it is not at all impossible that some clear-sighted benefactor of his race may establish a school as high in its purposes as the Carnegie Institution of Washington, but devoted entirely to engineering. This is what Dr. Waddell evidently had in mind, a school which will transcend existing schools in both the quality and the methods of instruction, and which will collate and make generally available the best data extant; and, through original research and investigation, give the world new laws.

HIGHER EDUCATION FOR CIVIL ENGINEERS.

An Address to the Engineering Society of the University of Nebraska, April 8, 1904.

By J. A. L. Waddell.

Young Gentlemen:

The subject of my remarks to-night is "Higher Education for Civil Engineers." Perhaps it is not the most suitable topic possible for an address to an assemblage of undergraduates, being more appropriate for a meeting of the Society for the Promotion of Engineering Education; nevertheless, I trust that it will interest you, for it treats of a matter of vital importance to the engineering profession, of which you are soon to become members.

It has been my good fortune and my pleasure often during the last twenty years to meet and lecture to the undergraduates of engineering schools; and on such occasions when the address was of a formal nature I usually confined my remarks to advice concerning young men's work both at the technical school and during the early years of practice. My reason for departing from this custom to-night is that I have about exhausted that subject, and do not desire to repeat myself. Moreover, if any of you care to receive such advice and to acquaint yourselves with my ideas of how to attain success in engineering, you will soon be able to do so; because my friend, Mr. John Lyle Harrington, Civil Engineer, is now engaged in compiling and editing some twenty technical papers of mine, with the discussions thereon, written during the last quarter of a century; and his book will contain most of my formal addresses to young engineers and students of engineering.

If I have made a mistake by choosing for this evening's discourse a subject somewhat in advance of students' thoughts, I shall endeavor to make amends by giving you to-morrow forenoon an informal talk concerning some of the most important works done by my firm during the last five years, and, if time permit, by describing some extremely interesting engineering investigations upon which we are just starting.

In connection with my subject the first question that is likely to enter your minds is whether any education higher than that now given to civil engineering students in the leading technical schools is really necessary or advisable. To this I answer " Yes—most decidedly yes." Perhaps a few of the engineering educators will disagree with me; but I know that some of the leading ones do not.

On this question I ought to be an authority; for not only does my firm employ constantly new graduates of technical schools from all over the United States as well as from Canada and Japan, but during my travels, which average in amount about fifty thousand miles per annum, I meet a great number of engineers with whom I discuss such matters as technical education. Nearly all of them have complaints to make concerning the deficiencies in the training of the recent graduates of technical schools.

By this they do not mean to convey the idea that engineering education has been deteriorating. Far from it! For the old engineers all recognize that since their college days great improvements therein have been effected, especially during the ten years that have elapsed since the inauguration of the Society for the Promotion of Engineering Education, to which most of this advancement is due.

But, great as may have been the strides in engineering education, the advance of the science and art of engineering has been far greater; and this divergence of progress is steadily increasing. The mass of technical literature which is of value to engineering students is now immense, and is constantly augmenting; while in my student days it was difficult to find enough good technical works to furnish us with proper text books for our course. Because of this accumulation of valuable engineering literature it is practicable to-day to give far better technical courses than were possible formerly; but the possibilities of improvement are by no means limited to results obtainable from the increased and improved engineering literature, as the latter is always of necessity far behind engineering practice.

While it would, no doubt, be impracticable to give engineering courses so closely in touch with current practice that they would make the students perfectly familiar with all of the latest developments in engineering, still it is possible for the faculty of a technical school to approximate to this *desideratum* by launching out ahead of the technical literature and securing for their students the latest information directly from practicing engineers. This procedure is certainly the most effective one possible for advancing the interests of engineering education.

It may be claimed that those engineers who complain of the insufficient training of recent graduates are merely cranks who are asking for the impossible, and that they would not be satisfied with any attainable training; but this is not true. Those of them whom I have in mind just now certainly stand at or near the head of the profession, and are reasonable, practical men. Complaints of this kind are not made ill-naturedly; but merely to state existing conditions that require betterment. Moreover, they are a good thing for our profession; if there were no tendency for the practicing engineers to make such complaints, it would indicate that perfection has been reached in the technical schools, which is certainly not the case.

Having spent six years of my life in teaching civil engineering, I naturally take an intense interest in everything relating to the development of that branch of our profession; and I make a point of meeting the professors of civil engineering whenever I can during my travels. In conversation with these gentlemen I often suggest improvements and reforms in technical education; and they nearly always agree that my suggestions are good but state that there is not sufficient time available for their adoption. That this is generally true I know only too well. Seventeen years ago in an exhaustive paper on Civil Engineering Education I advocated the adoption of five-year courses in civil engineering, and I have been harping upon this idea ever since. The time is surely coming when all first-class courses in civil engineering will occupy five years; and the day for inaugurating this change is not far distant. Its approach is heralded by the post-graduate courses that are becoming so common in technical schools; and the next advance will be to make these courses obligatory instead of optional.

Probably the first institution to inaugurate this change will be McGill University; for, unless I am decidedly mistaken, the faculty of that school is bending its energies toward the accomplishment of this purpose. It will then seem odd to see Canada leading the United States in such an important matter as engineering education. In truth, I am almost convinced that such is the case to-day; for the engineering course at McGill has for some time been rapidly and steadily improving. This much I can vouch for—the course in bridges is far in advance of any similar course given in the United States, or for that matter anywhere else in the world.

One objection raised to increasing the length of engineering courses to five years is that such action would work a hardship on many worthy young men of scant means and would render it impracticable for them to secure a technical education. Such a plea is a fallacy; for young men would still find some school where four-year courses are given; as to-day there are institutions where engineering is taught in three years. Again, if an impecunious young man can raise the money required for taking a four-year course, by a little extra effort he can probably raise enough for a five-year course. Moreover, it is constantly becoming easier for poor but worthy young men to secure financial aid in obtaining education.

Here let me digress a moment to make the statement that there is no better way for a financially successful man to aid mankind than by helping ambitious young men to secure thorough, practical education. Nor need such aid be given in the form of charity; for if the young man be honest as well as capable and energetic, the money can be lent instead of given him; and for several reasons the former method is decidedly better, principally because it does not injure the recipient's self-respect. By accepting notes at the current rate of interest for all moneys advanced and securing the loan by life insurance, the possibility of loss to the lender is reduced to a minimum. I have seen this method tried with fortunate results; and I recommend it to those successful men who desire to help others by the use of some of their accumulated wealth. The satisfaction that they will experience in the success of their protégés will transcend that from any other investment.

Among the most important deficiences noted by practicing engineers in the recent technical-school graduate are inability to express himself correctly and forcibly in either writing or speaking, lack of all ideas of system, inaccuracy in computations, ignorance of money values and economics, slovenliness in drafting, ignorance of what a drawing should contain to make it complete and serviceable, failure to understand the practical application of what he has learned in his technical course, and unacquaintance with numerous little practical things that he ought to have learned.

In commenting upon the current practice of instructing engineering students and its results, I desire you to understand clearly that my remarks are absolutely of a general nature, and refer in particular to no one institution of learning. And I especially want you to bear in mind that I have no intention of criticising the work of your professors. Of this you will probably hold me guiltless, when I confess to you that, much to my regret, I have never had an opportunity to learn anything concerning the character of the work done at the Nebraska State University.

That the study of the English language is sadly neglected in our technical schools nobody is likely to deny; for the English spoken by the majority of their graduates is atrocious; their letters are awkward, misspelled, and ungrammatical; and their ability to write reports, specifications, and contracts is practically *nil*.

Why should such a sad state of affairs as this exist, and with whom lies the blame? These questions are not difficult to answer.

The boys that enter technical schools are generally not well prepared, and the study in which they are invariably weakest is the English language. Most of them from early association speak ungrammatically, and but few of them have had proper training in spelling, grammar, and composition. Even the special preparatory schools fail to provide proper training in these essential studies; and the waiving of entrance examinations to technical institutions for graduates of such preparatory schools augments the trouble. Most technical schools give, or pretend to give, more or less instruction in English; but the courses are usually confined to the

Freshman year, and are looked upon by the students as of minor importance. The result is that they are neglected, and the boys make a point of studying for them only enough to pass; consequently, when it comes to writing anything original they fail to do themselves credit.

The study of English should be continued throughout the entire technical course, and should be carried even into the graduating thesis, making its proper wording and grammatical construction essential for graduation. Too much stress cannot well be laid on the importance of a thorough study of the English language. Given two classmate graduates of equal ability, energy, and other attributes contributory to a successful career, one of them being in every respect a master of the English language and the other having the average proficiency in it, the former is certain to outstrip the latter materially in the race for professional advancement.

Upon whom then lies the blame for this undesirable state of affairs? Primarily, it is upon the faculty for not insisting that the subject of English be given as much consideration as any other subject in the entire course; and, secondarily, upon the students for their flagrant neglect of this vitally important study.

Is it not generally acknowledged by all members of the profession, young and old, experienced and inexperienced alike, that the most eminent engineers are not those who have merely constructed large and important works, but those who in addition have by their writings recorded the results of their efforts and thus instructed others concerning how to undertake similar constructions? Such being the case, is it not evident that a complete and thorough mastery of one's native language is essential to the highest professional success?

Ponder seriously upon this matter, my young friends, and see whether you do not agree with me concerning the importance to each of you of a thorough and fundamental knowledge of your mother tongue; and if you do, take without delay the necessary steps to secure such knowledge.

Both the teaching and the learning of systemization at school are certainly extremely difficult; nevertheless, a certain proficiency therein may be attained by the students, if the professor will lecture to them on the subject; but each student should endeavor to perfect himself by spending a portion of one summer vacation in the office of some engineer, contractor, or company that is noted for the effective systemization of its works and records. When there, not only should he master the subject in all its details, but also he should make full notes upon it for future reference.

Accuracy and neatness in computation can be attained in the technical school if the professors are themselves accurate and neat in their work, and if they will invariably insist on their students being so. Most young men think that if they understand the method of solving a problem that is sufficient, even if the result be incorrect, and that it is a waste of time to check and correct calculations. No greater mistake could be made. No engineer can be truly successful who does not have all the work for which he is responsible checked and counter-checked, preferably by independent computers; and the man who fails at college to gather up all the loose ends and to make sure that no errors exist in his computations is not at all likely to develop into a careful and accurate practicing engineer.

Some students think that at school there is no necessity for dealing with dollars and cents, leaving such material things for their subsequent practice; and too often the professors either tacitly agree with them in this notion or else fail to correct the error.

Never probably since the days of the Pharaohs, when with slave labor those rulers built the great pyramids, has it been possible to divorce engineering from pecuniary considerations; and nowadays engineering, economics, and financiering are so closely allied that it is impossible to separate them on work of any magnitude. Consequently the much despised but almighty dollar should make itself conspicuous throughout every practical course in an engineering curriculum. Students should be forced to prepare with each of their designs a complete and minutely detailed estimate of cost, and should be made to understand that this is one of the essential features of the course of instruction.

A study of the principles of economics in all departments of designing is essential to every first-class course in civil engineering; and the students should be made to comprehend that the most successful engineer is he who can accomplish a certain result in a perfectly satisfactory manner with the least expenditure of money. Care should be taken to distinguish between true and false economy, and to instil into the students' minds the principle that the most economic construction is not that which at first costs least; but that which will do its work for an indefinitely long time, and in which the first cost plus the capitalized cost of maintenance and repairs is a minimum; also that it is better engineering to build a cheap, temporary, yet perfectly safe structure with the intention of replacing it later by a permanent one, than to construct a weak or scamped structure that has a false appearance of permanency.

The character of the drafting done by the average graduates of technical schools is decidedly below par; and there is no good excuse for this, because, with very few exceptions, students can be so taught the mechanical part of drafting that their efforts would pass muster in the offices of civil engineers and contracting companies. The ability to make neat drawings immediately after leaving school may mean many dollars in the pocket of the young engineer, which otherwise would not find their way there; and in truth it may often prove the cause of his being retained in a competition for a position with otherwise better equipped men. Fancy work is neither called for nor desired; but neat, plain work, especially free-hand, is of the utmost importance.

Very few young engineers, and, truth to tell, not all old ones, appreciate how complete every drawing should be made and what written notes it should contain. In our office we aim not only to indicate on all drawings every measurement necessary for construction, but also to write on them all special instructions for the contractors and generally a condensed specification. Such drawings prevent the contractors from being able to excuse themselves for an error by saying " we did not have the specifications at hand when we were doing the work," or " the specifications are so voluminous that the clause pertaining to this special point escaped our notice."

One of the greatest difficulties under which many engineering students labor is their failure to see the practical application of theory to actual engineering. The blame for this generally lies with the professors, who either are themselves ignorant of such practical application, or neglect to call the attention of their students to it. The remedy for the evil is to insist on the professors of technical schools being practical engineers as well as good teachers.

There are numerous little practical ideas, time and labor saving devices, and short cuts to results which a practical and experienced engineering professor can present to his students, and which will tend greatly to the amelioration of the characteristic greenness of the recent graduate when entering upon his professional career.

In addition to the subjects covered in the usual curriculum of the civil engineering school there are others of great importance that are either given nowhere or are inadequately treated in a few of the schools. Prominent among these are the following: Political Economy, Law, Business, History of Engineering, Oratory, Debating, Dictation, Specifications and Contracts, Graphics, Secondary Stresses, Economics, Science of Railroading, Geodesy, Least Squares, Instrumental Work, Architecture, Geology, Tunneling, and Dams. To this list might be added some other subjects which are often given, but which are capable of considerable extension; for instance, Metallurgy of Iron and Steel, Harbors, Canals, River Improvement, Sanitation, Water-Supply, Power-Transmission, Highway Engineering, Mechanical Engineering, Electrical Engineering, and Reinforced Concrete Construction.

Both lists are, no doubt, very incomplete; nevertheless they are amply large to show that there are many important branches of our profession which are either taught inadequately or are not taught at all in the technical schools of America.

But—some of you will remark—" Is it necessary for every engineering student to learn all of these branches? Surely in his active career he will confine his attention mainly to two or three lines, and in consequence will not need much instruction in the others!"

To this I would reply, "Certainly, no man can specialize in many branches of engineering work; but the student of a technical school does not know for which lines he is fitted or which specialty circumstance may induce him to adopt. Moreover, every specialty in engineering is more or less closely allied to all the other specialties; consequently it behooves a broad-gauge engineer to become somewhat familiar with all branches of engineering so as to act intelligently when his business involves him in other specialties than his own."

As an example of how the various branches of engineering are interwoven and allied, I would call attention to the facts that the bridge specialist in designing movable bridges always encounters mechanical engineering and sometimes electrical engineering; on the approaches to bridges he includes railroading; in the pavements of wagon bridges he touches upon highway engineering; in the protection of structures he meets with river improvement; in the machinery houses of swing spans he includes architecture; in the guarding of bridges against fire he encounters water-supply; i nthe switches, signals, and interlocking plant for movable bridges he meets with a special department of railway work; and in the testing of materials for superstructure he encounters chemistry and metallurgy. That this statement is no exaggeration my present work will bear witness, for my firm is to-day engaged on the designing and supervision of construction of a number of bridges in which all of the lines of work just mentioned are involved.

As another example, the railroad engineer encounters hydraulic problems in bank protection and pumping plants, architecture and structural engineering in round-houses and other buildings, sanitation in station-houses, bridge work in the structures for his line, mechanical engineering in interlocking plants, electrical engineering in repair-shop machinery, and highway engineering where his line passes through large cities.

Again, the hydraulic engineer trespasses on the ground of the architect in his power buildings, and on that of the structural engineer in the steel roof-trusses for them, encounters mechanical engineering in his pumping machinery, and has to fall back upon chemistry in testing the qualities of water.

There is no need for further illustration; for enough examples have been quoted to show that all the main divisions of engineering are interdependent and inseparable.

Now while it is eminently proper, and in truth necessary, for a specialist to call to his aid experts in other lines when his practice involves engineering in other branches than his own, it is highly inadvisable that he be absolutely ignorant of everything in those other lines. Surely he ought to understand the fundamental principles which govern the engineering work therein, even if he has to entrust the details to his associated engineers!

But how can a man become acquainted with all branches of engineering? Certainly not by attending the technical schools with their present curricula, nor by endeavoring to practice in the various branches. The brevity of life makes these methods impossible at present, although it might not have done so twenty-five or thirty years ago, when the amount of accumulated knowledge concerning engineering was ever so much smaller than it is to-day.

It is true that but few young men would be willing to study enough to post themselves on all of the main branches of engineering; and in fact the large majority of the students of technical schools appear to believe that the shorter and easier the course leading to their degree the better for them. Nevertheless, there are almost invariably in very class a few who are eager to secure a broad and thorough education in spite of all the labor involved in attaining it; and it is a matter of serious regret that such men cannot now accomplish their desire.

Can there be evolved any means for enabling these young men to satisfy their praiseworthy aspiration? Yes; and later on I shall indicate it to you; but first let us consider what can readily be done to make more practical and thorough the courses given to-day in the principal technical schools.

Much could be accomplished by raising the requirements for entrance so as to ensure that each member of the Freshman class is fairly well posted in English and the other studies usually included in an ordinarily good American education. He need not be a master in all these lines, but he should be well grounded in them.

Again, a large portion of the present work of the Freshman year might satisfactorily be required for entrance to the course, and the time thus saved could be devoted to work now occupying the Sophomore and even the Junior years, thus leaving later on time for higher studies.

More time, too, could be gained for this purpose in many schools by omitting unnecessary studies from the curricula, notably the foreign languages.

One of the most effective ways is to increase the number of working months in the year from eight or nine to eleven. This need not involve a hardship for either the students or the professors, because the summer months could be devoted to field work, which would afford rest for weary brains and would build up weak constitutions, while by employing more professors in the faculty the extent of each one's annual work could be reduced to any reasonable amount. The most effective method of all, however, is to increase the duration of the course to five years.

But all the additional time thus gained would not be sufficient to make each student a master of the theory and conversant with the practice in all branches of civil engineering, although the course that could be thus given would cover nearly twice as much ground as the average technical course at the present time. The strictly technical studies now occupy but little more than two years; consequently another year, when the student's capacity for work is so greatly increased by his previous study, would probably double the technical knowledge of the present graduate.

Courses such as just suggested are going to be given in the not very distant future; and they are in reality almost a necessity to-day. The rapid advances in engineering science are calling loudly for better prepared young men to fill for a short time subordinate positions and then advance rapidly to places of trust and responsibility; and, as in all walks of life in this great country of ours, the supply is certain quickly to meet the demand.

The method that I propose for the advancement of engineering education in America to the highest possible plane, and to enable the studious, energetic, and ambitious graduates of all technical schools to continue their engineering studies in both theoretical and practical lines to any extent they may desire is as follows:

Let one of America's multi-millionaires found and endow most liberally a post-graduate school of civil engineering, in which would be employed as officers, professors, and lecturers men of the highest talent in the country, irrespective of what it may cost, and let the institution be established and equipped upon the broadest lines. There should be a comparatively small corps of permanent professors, but the principal instruction should be given by practicing engineers chosen from the best known and most competent in the profession. In order to secure them it might be necessary to reimburse them for their time even at maximum consultation rates. It would not do to make a practice of paying much less, as each instructor should be placed upon his mettle in order to ensure the best possible results from his work. In some cases this might not be practicable, if the instructor felt that his work was something of a "charity job"; but if he were convinced that neither pecuniarily nor professionally would he be losing anything by teaching, he would be certain to put forth his best efforts and endeavor to teach each student as much as possible of the best he knows.

The function of the permanent professors would be to keep the various departments active at such times as the lecturers would be absent, and ensure that the students would always have some one to refer to concerning their studies and investigations. It should also be the business of the permanent professors to study current engineering literature, and to excerpt therefrom and deliver in the form of lectures everything likely to be of real value to the students, as well as to call their attention to the articles which each one ought to read. They should also teach the students the knack of reading current technical literature so as to obtain its gist with minimum effort and loss of time.

They should prepare a work discussing engineering literature that would include all technical books which are in accord with current practice, show their scope, and indicate their good and their bad points. This treatise should be re-written from time to time so as to keep it up to date.

The permanent professors should also be required to translate or assist in the translation of all engineering books in foreign languages, which, in the opinion of competent experts, would prove useful to American engineers or to the students of the institution.

The president or director of such a school should be the most broad-gauge, profound, and progressive engineer in the entire country, and the governing body or trustees should look to him to see that the maintenance and development of the course of instruction are such as to accomplish to the utmost the great object of the school's existence.

Original investigation by both the professors and the students should be provided for and encouraged in every way, and the results should be published in an official paper of the institution. These investigations should be of an eminently practical nature and calculated to improve engineering practice or to lead to valuable discoveries in technical science.

A great testing laboratory, the most complete and perfect in the world, should be an adjunct of this institution, and its constant use should form a part of the curriculum.

Designing should be the characteristic feature of the course of instruction, and should be employed in every course where its use is practicable. Nothing will teach a man a subject involving engineering construction more thoroughly than the making of a complete and accurate design for some special case, unless perhaps it be the teaching of that subject to technical students. All designing should be done in the class room under the direct supervision of experts, and in the same detailed and thorough manner that is, or should be, characteristic of designing done in the offices of consulting engineers.

One prominent feature of the curriculum should be the study of both pure and applied mathematics, not only for the purpose of refreshing the memories of the students and supplementing previous faulty instruction, but also in order to carry this study farther than is customary in technical schools. The main object of the course, though, should be to teach the students to do original mathematical work, thus enabling them to solve difficult problems in the highest branches of engineering.

Another prominent feature of the course should be numerous visits by the professors and students, both together and separately, to works under construction, finished structures, and industries of all kinds; and special facilities for studying these should be arranged for in advance by the president or the governing board.

No special length of time should be set for the duration of the course, but each student within certain reasonable limits should be given the privilege of choosing his subjects and the time for taking them. It would be well to arrange to give to those who do a certain amount of studying at the institution certificates to that effect, and to those who pass a satisfactory examination in one of a number of prescribed courses the degree of Doctor of Science or Doctor of Engineering, as the case may be; for the instruction given at such a school would certainly be as profound as that offered by any institution of learning in the world; and those fully profiting by it would most decidedly be worthy of a doctor's degree.

Let us now consider briefly some of the courses that I would advocate giving in such a post-graduate school of engineering. It is not my intention to try to make these suggestions at all complete, but merely to outline some of the possibilities for extending engineering education.

A knowledge of political economy is of great value to the civil engineer in his relations with the government (national, state and municipal), with capitalists and corporations, and with manufacturers.

In acting for the government or in dealing with it, a thorough knowledge of its nature and functions, the extent of its control over constructions, the relation between its fiscal and its engineering departments, and its control over and obligations to the public, is essential to the successful engineer.

In dealing with common carriers and other quasi-public corporations, a thorough knowledge of their relation to the public, their responsibility to the government, and their organization and management, is of the greatest importance.

The engineer for a manufacturing concern should be thoroughly conversant with the operation of the law of supply and demand, with the relations between capital and labor, with the theories of competition, and with the organization of industries.

All these things and many others that come under the head of political economy should be taught in the proposed post-graduate school.

A general knowledge of law in its relation to contracts, organization of companies, rights of corporations, and many other important matters connected directly or indirectly with engineering work, is essential to the highest professional success.

The fundamental principles of business should be taught to all engineering students, and they should be instructed carefully in respect to all such matters as stocks, bonds, and other securities, and the floating of same. Even such an elementary subject as the keeping of accounts should not be ignored.

Concerning the history of civil engineering I need say nothing here except that it should form a part of the curriculum of every technical school. Possibly many of you know that I am making a systematic and determined effort to induce the Society for the Promotion of Engineering Education to undertake the preparation of an exhaustive history of civil engineering in all its branches. Thus far nothing has occurred to make me despair of success in the accomplishment of this purpose.

But few technical men are fluent speakers, and as it is often the engineer's province to persuade capitalists into the undertaking of enterprises, or to argue in defense of one's rights in competition or of one's clients in legal controversy, a knowledge of oratory and experience in debate must be of great service in one's professional career; consequently the study and practice of these matters should be given due attention in the proposed post-graduate school.

The ability to dictate readily to a stenographer well expressed letters, descriptions, contracts, and specifications is enjoyed by very few engineers, and these few did not obtain their knowledge of this accomplishment at the technical school, but through long continued effort, much patience, and numerous discouragements. Every engineering student should be drilled in dictation until he becomes proficient.

The writing of first-class specifications and contracts is an art that cannot be acquired except through experience; nevertheless its acquisition can be hastened materially by a thorough drill at the technical school in the underlying principles of such writings, as well as in the practice of their composition.

In American schools of engineering the study of graphics is confined almost exclusively to the determination of stresses in framed structures; but in Europe it is carried much farther, entering into almost all kinds of computations. The graphical calculations of a highly educated German or Swiss engineer are beautiful to contemplate; and although it may not be advisable to utilize graphics in practice to the extent that these foreign engineers are inclined to, nevertheless, in my opinion, American technical schools have much to learn in this particular from those of Continental Europe. On this account it would be well to include in the proposed curriculum an elaborate course in higher graphics.

The subject of economics is one that is intimately related to every branch of civil engineering, and its importance is such that not only, as previously stated, should it receive due attention in the study of all such branches, but also it is deserving of a special course, in which its relations to all important professional and business affairs are expounded.

Few American engineers pay much attention to secondary stresses in framed structures, but European engineers are trained on their theory; and while it is true that the best way to treat secondary stresses is to avoid them in one's designs, still a comprehensive knowledge of their cause and magnitude would enable one to do so to far better advantage; hence a course in their theory should be given in our post-graduate school.

As far as I know, the science of railroading is not taught in any technical school, the elementary principles and practice of surveying and construction constituting the extent of the course in that subject. The science of railroading pertains to more abstruse subjects, such as the adjustment of grades and curves to traffic; the laying out of terminal yards for economical handling of cars; the reconstruction of cheap roads so as, with minimum interruption to traffic, to change them into first-class trunk lines; the economic maintenance of track and rolling stock; the relations that motive power, car equipment, rails, ties, ballast, speed, and volume of traffic bear to each other; and how changes in any one of these features affect the rest. A thorough course in all such details of railroading would be of great value to the student and of the utmost importance to the railroad systems of the country.

The true science of bridge design does not receive much attention in technical schools, or at least it is only its elementary features that are treated. The reason for this is not lack of proper books, but want of time. In our post-graduate school there should be given a course in bridges far surpassing in extent, thoroughness, and excellence any course on the subject yet given or even contemplated.

The new types of steel-and-concrete bridges should not only be covered in the course; but also the permanent professors both by experimentation and mathematical investigations should establish a proper theory for the designing of such structures.

Substructure and foundations should be treated much more elaborately than is customary in other technical schools.

The study of geodesy in both theory and practice, with the necessarily closely associated theory of least squares, should be given proper attention.

A much more elaborate course in instrumental work and measurements of precision than is usual should form a part of the curriculum: and all the latest and most complicated types of surveying instruments should be described in the class room and used in the field. A student's knowledge of an instrument should not be considered complete until he has learned to take it apart, clean it, put it together, and bring it into perfect adjustment.

Measurements of precision, equal in accuracy to those performed by the leading engineers on important bridge work, should be made by the students under the direct supervision of expert instructors.

An elementary but complete course in architecture, especially as it relates to engineering constructions, should form a part of the curriculum; and special attention should be paid to æsthetics in designing.

A sound, practical, working course in geology, mineralogy, and allied subjects should not be omitted.

A special course should be given on tunneling, and it should include the designing of tunnels of all kinds to meet all possible conditions.

There should be also a thorough course on the designing and construction of dams of every description.

In the course on the metallurgy of iron and steel the student should obtain a thorough acquaintance with the mechanical processes and the chemistry of their manufacture according to the latest practice; and a full description of all previous and abandoned methods should be given, as a knowledge of what has been done in the past often saves a great amount of labor when an endeavor is made to improve upon present methods; and long disused plans are frequently re-invented at great expense.

A knowledge of the action of iron and steel under ordinary working conditions is essential to the proper use of these metals in designing. A general idea thereof obtained from a few tests and lectures, such as is commonly gained by the engineering student, serves principally to befog the mind of the young engineer, and leaves him wholly unprepared to handle problems involving rapid vibration or heavy shock. On this account the testing of these metals in various forms and under differing conditions should be included in the course of instruction.

The designing and construction of harbors and canals of all kinds and the improvements of rivers under all possible conditions should be treated much more elaborately than is customary in technical schools; and hydraulic experiments with the latest and most improved types of current meters should be made by each student in the class.

The important subject of water supply should be taught in full detail, and experiments on the flow of water in pipes and a study of bacteriology should constitute portions of the course.

An exhaustive study of sanitary engineering in all its important features should be included as a part of the curriculum, and sewage disposal should be studied thoroughly by both professors and students for the purpose of affecting much needed improvements in that branch of engineering science.

Power transmission by the latest and most economical methods should also be taught.

Highway engineering should not be neglected, and the effect of good roads upon the development of a country or a district should be investigated.

No civil engineering curriculum is complete without elementary but thorough courses in mechanical engineering and electrical engineering; consequently there should be special departments for them in our post-graduate school; and the professors in these branches should endeavor to evolve a complete set of scientific principles for designing the details of machinery, corresponding somewhat in style and extent to the principles that have been established for the designing of steel bridges.

The advantages to be gained by attendance at such a post-graduate school as the one advocated are almost beyond expression! A degree from such a school would always insure rapid success for its recipient. Possibly for two or three years after taking it a young engineer would have less earning capacity than his classmates of equal ability from the lower technical school, who had gone directly into actual practice. However, in five years he certainly would have surpassed them, and in less than ten years he would be a recognized authority, while the majority of the others would be forming the rank and file of the profession with none of them approaching at all closely in reputation the more highly educated engineer.

But if the advantages of the proposed school to the individual are so great, how much greater would be its advantages to the engineering profession and to the entire nation! After a few years of its existence there would be scattered throughout the country a number of engineers more highly trained in the arts and sciences than any technical men who have ever lived; and it certainly would not take long to make apparent the impress of their individuality and knowledge upon the development of civil engineering in all its branches, with a resulting betterment to all kinds of constructions and the evolution of many new and important types.

When one considers that the true progress of the entire civilized world is due almost entirely to the work of its civil engineers, the importance of providing the engineering profession with the highest possible education in both theoretical and practical lines cannot be exaggerated.

What greater or more worthy use for his accumulated wealth could an American multi-millionaire conceive than the endowment and establishment of a post-graduate school of civil engineering such as I have to-night attempted to describe!

Should this address of mine by reaching the eye of one of those multi-millionaires be the means of inducing him to endow such a school, I would consider its preparation to be the greatest work of my entire professional career!

COMMENT.

The idea of engaging practicing engineers of high standing to give instruction in the graduate school is, of course, excellent, and will, no doubt, be adopted as the graduate courses increase in number and importance; but their work should be confined to the instruction in the practical work of designing. The theory is best taught by the instructor who devotes himself entirely to educational work, for he has at his disposal the time necessary for original research and for the detailed study of the finer theoretical points. A successful practitioner cannot devote one portion of his time entirely to teaching and another to practice, but must take such time as he can, generally a brief period or two each year, for the educational work.

Neither is it essential that the practitioner be paid so well for time devoted to teaching as he is for time spent in practice, for engagement by a prominent institution, especially by such an institution as Dr. Waddell has suggested, would add greatly to his prestige, and prestige has money value.

Many of our better institutions which are now offering graduate courses might well give the matter of employing practicing engineers serious consideration. Even a week or two at the end of each course devoted to designing under the direction of an energetic and able engineer would strengthen the work immeasurably. The regular instructors should, of course, possess a sound knowledge of practice, but the labor of imparting a knowledge of the various subjects to students of various types and capacities must occupy the major portion of their time and thought, while the practitioner's energies are chiefly devoted to design and construction, consequently he is fresh for the teaching and should, if he be tactful, be able to command the student's attention and to quicken his energy.

The practitioner must be employed to assist the professor, not to instruct him. There must be no idea of superiority on his part or the result upon professor and student alike will be far from desirable.

It does not seem to be desirable to teach practice so thoroughly in the schools that the graduate, or even the recipient of a higher degree, may be considered an engineer prepared for responsible work. If any man have a strong predilection for any particular branch of engineering, he can, if he be persistent, obtain employment in that line and thus obtain his knowledge of construction. The graduate school should, however, afford the opportunity to obtain all knowledge extant pertaining to the theory of the subject. No undergraduate course, within the editor's knowledge, gives more than the barest essentials of the theory in bridge work. Arches, suspension bridges, cantilever bridges, and continuous girders receive a very limited amount of attention. The theories of their design must be obtained in the graduate school or by unaided effort, and it would be a serious mistake to substitute for them courses in the current practice of designing and detailing the lower order of structures. If the student have time and means at his disposal, so that compensation for his labor is not a consideration, he may readily obtain employment which will teach him the practice of his chosen specialty far more satisfactorily than it can be done in school. For instance, if he choose bridge work, he may enter the office of a consulting engineer, where he will see and take part in a variety of work, or he may go to the shops and see the work detailed and fabricated as well as designed. Both the amount and the variety of work he will thus be enabled to study will be far greater than he could obtain in the school. The opportunity to see the structures fabricated is of very large value in itself. The work is real, tangible, and has a present as well as a future purpose, hence takes better hold of both the interest and the memory.

It would, however, be quite as unwise to leave all the instruction in practice out of the technical courses as to endeavor to make it complete would be, for the work the average graduate obtains does not afford exercise for his knowledge of theory, and it is frequently half forgotten before he has the opportunity to employ it.

The present technical courses leave so much to be desired that it is difficult to suggest graduate courses suited to the needs of the recent graduate. When the preparatory work and the undergraduate courses are improved so that sound instruction is given in all principal branches before the baccalaureate degree is conferred, the graduate courses offered will comprise advanced work only, but at present they should contain fundamental instruction in branches which are crowded out of the undergraduate courses by essential but non-technical subjects. The courses should be divided into groups of closely related or allied subjects, each designed to prepare the student for some special line of work, and each leading to a higher degree.

As the students of the graduate school will come from various institutions or from practice, it would seem advisable to precede the work in each course by a hasty but comprehensive review of the work preceding it, in order to insure a good foundation. The students come equipped with a sound knowledge of fundamental principles, well developed methods of work, years of discretion, and a well defined purpose, hence the work should be pursued with extraordinary vigor. The courses should be planned, not for the average or the dull man, but for able, well grounded students, and the work done in a year should far surpass in both quality and quantity the amount required for a similar period during the undergraduate course.

The history of the development of a science should be reviewed, at the beginning of a course, the failures as well as the successes being brought up for consideration. This will serve to direct the work upon right lines and save repeating investigations. It must not be assumed, however, that a failure is conclusive. The early experiments and investigations relating to single-phase, alternating-current electrical machinery failed to bring forth useful results, but after the subject lay untouched for many years, recent investigations resulted in the construction of machinery of the highest promise.

Exceedingly broad and thorough preparation should be demanded for entrance upon the highly specialized graduate work, otherwise the result will be men very highly educated along narrow lines and ill-equipped except as technists. Broad culture is essential to success in the highest sense and no pains should be spared to make this plain, though the purpose of the graduate school is to train specialists.

For the bridge engineer the courses offered should comprise an exhaustive study of arches; suspension bridges and their stiffening trusses; cantilever bridges; movable bridges of the various types; the construction of foundations by the pneumatic and the freezing processes, by open dredging, and by the use of coffer dams; studies in the metallurgy of iron, steel, and other alloys; the theory of the various types of reinforced concrete construction; the preservation of timber; the chemistry of cement; the effects of impact, vibration, and the reversal of stresses on the various materials of construction; and the chemistry of protective coverings and the agents which destroy them.

The architectural engineer requires courses in architecture, foundations, the metallurgy of iron and steel, the chemistry of cement, the theory of reinforced concrete construction, arches, heating and ventilation, lighting, the effects of impact and vibration, fire-proofing, insurance, the construction and operation of elevators, and the chemistry of preservative coatings.

The engineer who makes water supply and sewerage his specialty, requires a knowledge of meteorology, hydraulics, masonry dams and conduits, pumping machinery, the chemistry of cement, the metallurgy of iron and steel, bacteriology, botany, the chemistry of water softening and purification, the chemistry of sewage disposal, and the laws governing riparian rights.

The specialist in railroading, in power engineering, in the recently developed branch of street railway and rapid transit engineering, in municipal engineering, in river and harbor work, and in similar well-defined branches, requires courses similar to those outlined above.

In all courses the preparation of specifications and contracts should be required, and careful attention should be given to their English and to their conformity to the laws of contracts.

It is not many years, comparatively, since instruction in civil engineering as a profession was first offered. Well organized courses leading to a professonal degree are of still more recent origin, but are now almost as common as the ordinary college course. Indeed, an engineering education is rapidly coming to be considered the best possible preparation for business and manufacturing and the number of students in the engineering courses is rapidly approaching that of collegiate students. Hence it is difficult to understand why graduate courses have not been established in engineering as they have been in chemistry, geology, physics, economics, and other sciences. In these lines courses leading to a doctor's degree and requiring three years' resident study and research after the receipt of the baccalaureate degree have long been established. The demand for highly trained engineers now requires the establishment of such courses as those outlined above, and they will, no doubt, be offered in the very near future. They should lead to the degree of Doctor of Engineering, for they are certainly equivalent to the requirements for the degree of Doctor of Philosophy, Doctor of Literature, or Doctor of Science. The literature necessary for instruction in such courses is available, suitable instructors are available, and the profession demands the higher education; consequently, it cannot be much longer postponed.

The establishment of an institution such as Dr. Waddell has suggested, with ample equipment and an able faculty, would be of untold benefit to the country. The further development of the science of engineering would largely lie with its faculty and graduates. Its sphere of usefulness would be incomparably great, for it would lead the advance in the profession which has done more than all others to place the United States in the van of civilized nations.

THE RELATIONS OF CIVIL ENGINEERING
TO
OTHER BRANCHES OF SCIENCE.

AN ADDRESS TO THE INTERNATIONAL CONGRESS OF ARTS AND SCIENCE
AT THE UNIVERSAL EXPOSITION, ST. LOUIS, MO.

SEPTEMBER 21, 1904.

By J. A. L. WADDELL.

INTRODUCTORY NOTES.

Early in 1904 the Organizing Committee of the International Congress of Arts and Science which was formed under the auspices of the Louisiana Purchase Exposition invited Dr. Waddell and Prof. Lewis M. Haupt to represent the profession of civil engineering and address the Congress upon "The Relations of Civil Engineering to Other Branches of Science" and "Present Problems of Civil Engineering." Prof. William H. Burr was chairman of the Committee on Civil Engineering for the Congress and presided over the meeting at which these addresses were read.

What constitutes the profession of civil engineering has of late been a much discussed question. Engineers have found it advantageous to specialize, and certain groups of specialists have organized societies which are devoted to the advancement of the corresponding groups of special subjects. The American mining engineers perfected their organization at an early date, the civil engineers soon after, and more recently other groups such as the mechanical engineers, the electrical engineers, the heating and ventilating engineers, and the naval engineers and architects have organized societies which have proved their usefulness and occupy positions of national importance. Within each of these societies there are groups of men who are specializing along still narrower lines, and it seems probable that still other societies of very restricted scope will spring up in the course of time, though it would appear that further sub-division would be uneconomical. Each organization must have a characteristic name, and, in course of time, this name is firmly established and the further division of the profession is generally recognized. Thus it would seem that the division of engineering is merely one of convenience, but it is not so simple as it appears, for one engineer may be engaged in several lines and a man may be an active member of several societies. There is no doubt, however, that the sub-divisions of the profession will remain detached in this country, for both engineers and the public have generally accepted them.

Dr. Waddell has outlined broadly the present relations between the civil engineer and the pure scientist. He struck the key-note when he called attention to the fact that these relations are recent in origin and that they are rapidly growing closer. Engineering grows more complex and more important every year, hence its needs are more generally recognized by the investigator; at the same time the engineer is increasingly dependent upon the work of the pure scientist.

The character of the relations between the engineer and the physicist, the chemist, the geologist and the other scientists depends chiefly upon engineering education. In the first place, the greater number of original investigators are teachers, and their students are not only taught the discovered laws of nature, but they are inspired with an ever-growing interest in the discoveries and theories of the investigator. An interest so established clings to the engineer throughout his life and resists the tendency of his strictly professional work to absorb all his attention. Well trained engineers teaching courses of high character keep in close touch with the investigators and thus are able to direct the interest of students to the most advanced research. Students so taught are very sure to maintain that interest, to keep closely informed upon the progress of the investigator, and to make use of the best and freshest information. Those engaged in original research are in turn benefited by keeping in close touch with the engineer's applications of the most recent discoveries. Thus the work of the pure and the applied scientists is constantly growing more dependent upon their combined efforts.

THE RELATIONS OF CIVIL ENGINEERING TO OTHER BRANCHES OF SCIENCE.

An Address to the International Congress of Arts and Science at the Universal Exposition, St. Louis, Mo., September 21, 1904.

By J. A. L. WADDELL.

The topic set for this address is "The Relations of Civil Engineering to Other Branches of Science." In its broad sense civil engineering includes all branches of engineering except, perhaps, the military. This is its scope as recognized by two of the highest authorities, viz., the American Society of Civil Engineers and the Institution of Civil Engineers of Great Britain; for these two societies of *Civil* Engineers admit to their ranks members of all branches of engineering. It is evident, though, from a perusal of the Programme of this Congress that the Organizing Committee intended to use the term in a restricted sense, because it has arranged for addresses on mechanical, electrical, and mining engineering. But what are the proper restrictions of the term is, up to the present time, a matter of individual opinion, no authority having as yet attempted definitely to divide engineering work among the various branches of the profession. To do so would, indeed, be a most difficult undertaking; for not only do all large constructions involve several branches of engineering, but also the profession is constantly being more minutely divided and subdivided. For instance, there are recognized to-day by the general public, if not formally by the profession, the specialties of architectural, bridge, chemical, electrical, harbor, highway, hydraulic, landscape, marine, mechanical, metallurgical, mining, municipal, railroad, and sanitary engineering, and possibly other divisions; and the end is not yet, for the tendency of modern times in all walks of life is to specialize.

Between Tredgold's broad definition of civil engineering, which includes substantially all the applied sciences that relate to construction, and the absurdly narrow definition which certain engineers have lately been endeavoring to establish during the course of a somewhat animated discussion and which would confine civil engineering to dealing with stationary structures only, there must be some method of limitation that will recognize the modern tendency toward specialization without reducing the honored profession of civil engineering to a mere subdivision of applied mechanical science.

Without questioning in any way the correctness of the Tredgold definition, civil engineering will be assumed, for the purposes of this address, to include the design and construction of bridges; extensive and difficult foundations; tunneling; retaining walls, sea-walls, and other heavy masonry; viaducts; wharves; piers; docks; river improvement; harbors and waterways; water supply; sewerage; filtration; treatment of refuse; highway construction; canals; irrigation works; dams; geodetic work; surveying; railways (both steam and electric); gas works; manufacturing plants; the general design and construction of plants for the production of power (steam, electric, hydraulic, and gaseous); the general design and construction of cranes; cableways, breakers, and other mining structures; the heavier structural features of office buildings and other large buildings that carry heavy loads; the general problems of transportation, quarrying, and the handling of heavy materials; and all designing and construction of a similar nature.

In contradistinction, mechanical engineering should include the design and construction of steam engines, machine tools, locomotives, hoisting and conveying machinery, cranes of the usual types, rolling-mill machinery, blast-furnace machinery, and, in fact, all machinery which is designed for purely manufacturing purposes.

Electrical engineering should include all essentially electrical work, such as the designing, construction, and operation of telephone and telegraph lines; electric light plants; dynamos; motors; switchboards; wiring; electric devices of all kinds; transmission lines; cables (both marine and land); and storage batteries.

Mining engineering should include all under-ground mining work; means for handling the products of mines; roasting, smelting, milling, stamping, and concentrating of ores; drainage and ventilation of mines; disposal of mine refuse; and similar problems.

It is impracticable to draw hard and fast lines between the various branches of engineering, because, as before indicated, nearly all large constructions involve several specialties, consequently no specialist can confine his attention to a single line of work to the exclusion of all other lines. For instance, the bridge engineer encounters mechanical and electrical engineering problems in designing movable bridges; railroading in approaches to bridges; river improvement in the protection of piers and abutments; highway construction in the pavement of wagon bridges; architecture in the machinery houses of swing spans; hydraulic engineering in guarding bridges against fire; and chemistry and metallurgy in testing materials. The railroad engineer encounters architecture and structural engineering in depots, roundhouses, and other buildings; hydraulic problems in pumping plants and bank protection; mechanical engineering in interlocking plants; and electrical engineering in repair-shop machinery. The mining engineer invades the field of mechanical and electrical engineering in his hoisting, ventilating, and transporting machinery; deals with civil engineering in his surveys; and encounters chemistry and metallurgy in testing ores. Similarly it might be shown that all branches of engineering overlap each other and are interdependent.

It was the general opinion among scientists not many years ago that engineering was neither a science nor a profession, but merely a trade or business; and even to-day there are a few learned men who hold to this notion—some of them, *mirabile dictu*, being engineers; but that such a view is entirely erroneous is now commonly conceded. He is an ill-informed man who to-day will deny that civil engineering has become one of the learned professions. Its advances in the last quarter of a century have been truly gigantic and unprecedented in the annals of professional development. It certainly can justly lay claim to being the veritable profession of progress; for the larger portion of the immense material advancement of the world during the last century is due primarily and preeminently to its engineers.

It must be confessed that half a century ago engineering was little better than a trade, but by degrees it advanced into an art, and to-day, in its higher branches at least, it is certainly a science and one of the principal sciences.

The sciences may be divided into two main groups, viz., "Pure Sciences" and "Applied Sciences."

The "Pure Sciences" include:—

1st. Those sciences which deal with numbers and the three dimensions in space, the line, the surface, and the volume, or in other words "Mathematics."

2d. Those sciences which deal with inorganic matter, its origin, structure, metamorphoses, and properties; such as geology, petrology, chemistry, physics, mineralogy, geography, and astronomy.

3d. Those sciences which deal with the laws, structure, and life of organic matter; such as botany, zoology, entomology, anatomy, physiology, and anthropology.

4th. The social sciences; such as political economy, sociology, philosophy, history, psychology, politics, jurisprudence, education, and religion.

"Applied Sciences" include:—

1st. Those which relate to the growth and health of organic matter; such as medicine, surgery, dentistry, hygiene, agriculture, floriculture, and horticulture.

2d. Those which deal with the transformation of forces and inorganic matter, viz., the various lines of engineering,—civil, mechanical, electrical, mining, marine, chemical, metallurgical, architectural, etc.

3d. Those which relate to economics; such as industrial organizations and manufactures, transportation, commerce, exchange, and insurance.

Some writers make no distinction between the terms "Political Economy" and "Economics," but in this address they are divided, the former relating to broad subjects of national importance and the latter to minor matters and to some of the details of larger ones. For instance, currency, the national debt, banking, customs, taxation, and the subsidizing of industries pertain to "Political Economy," while economy of materials in designing and of cost of labor in construction, supplanting of hand power by machinery, systemization of work of all kinds, adjustment of grades and curvature of railroads to traffic, and time and labor saving devices come under the head of "Economics."

The distinctions between the pure and the applied sciences are at times extremely difficult to draw, for one science often merges almost imperceptibly into one or more of the others.

The groups of pure sciences that have been enumerated may be termed

The Mathematical Sciences,
The Physical Sciences,
The Physiological Sciences, and
The Social Sciences,

while the groups of applied sciences may be called

The Organic Sciences,
The Constructive Sciences, and
The Economic Sciences.

In what follows the preceding nomenclature will be adopted.

The terming of engineering the "Constructive Science" is a happy conception, for engineering is truly and almost exclusively the science of construction. The functions of the engineer in all cases are either directly constructive or tend toward construction.

The engineer has ever had a due appreciation of all the sciences, imagination to see practical possibilities for the results of their findings, and the common-sense power of applying them to his own use.

Pure science (barring perhaps political economy) is not concerned with financial matters, and its devotees often look down with lofty disdain upon everything of a utilitarian nature, but engineering is certainly the science most directly concerned with the expenditure of money. The engineer is the practical man of the family of scientists. While he is sufficiently well informed to be able to go up into the clouds occasionally with his brethren, he is always judicious and comes to earth again. In all his thoughts, words, and acts he is primarily utilitarian. It is true that he bows down to the goddess of mathematics, but he always worships from afar. It is not to be denied that mathematics is the mainstay of engineering; nevertheless the true engineer pursues the subject only so far as it is of practical value, while the mathematician seeks new laws and further development of the science in the abstract. The engineer does not trouble himself to consider space of four dimensions, because there are too many things for him to do in the three-dimension space in which he lives. Non-Euclidian geometry is barred from his mind for a fuller understanding of the geometry which is of use to ordinary mankind. The mathematician demonstrates that the triangle is the sole polygonal figure which cannot be distorted, while the engineer, recognizing the correctness of the principle, adopts it as the fundamental, elementary form for his trusses. The mathematician endeavors to stretch his imagination so as to grasp the infinite, but the engineer limits his field of action to finite, tangible matters.

The geologist, purely studious, points out what he has deduced about the construction of the earth; but the engineer makes the mine pay.

The chemist discovers certain facts about the effects of different elements in alloys; but the engineer works out and specifies a new material for his structures. Again, the chemist learns something about the action of clay combined with carbonate of lime when water is added, and from this discovery the engineer determines a way to produce hydraulic cement.

The physicist evolves the theory of the expansive power of steam, and the engineer uses this knowledge in the development of the steam engine. Again, the physicist determines by both theory and experiment the laws governing the pressures exerted by liquids, and the engineer applies these laws to the construction of dams and ships.

The botanist with his microscope studies the form and construction of woods, while the engineer by experimentation devises means to preserve his timber.

The biologist points to bare facts that he has discovered, but the engineer grasps them and utilizes them for the purification of water supplies.

In short, the aim of pure science is discovery, but the purpose of engineering is usefulness.

The delvers in the mysterious laboratories, the mathematical gymnasts, the scholars poring over musty tomes of knowledge, are not understood by the work-a-day world, nor do they understand it. But between stands the engineer with keen and sympathetic appreciation of the value of the work of the one and a ready understanding of the needs and requirements of the other; and by his power of adaptability he grasps the problems presented, takes from the investigators their abstract results, and transforms them into practical usefulness for the world.

The work of the engineer usually does not permit him to make very extensive researches or important scientific discoveries; nor is it often essential to-day for him to do so, as there are numerous investigators in all lines whose object is to deduce abstract scientific facts; nevertheless there comes a time occasionally in the career of every successful engineer when it is necessary for him to make investigations more or less abstract, although ultimately utilitarian; consequently it behooves engineers to keep in touch with the methods of scientific investigation, in order that they may either perform desired experiments themselves, or instruct trained investigators how to perform them.

The engineer must be more or less a genius who invents and devises ways and means of applying all available resources to the uses of mankind. His motto is "utility," and his every thought and act must be to employ to the best advantage the materials and conditions at hand. To be able to accomplish this object he must be thoroughly familiar with all useful materials and their physical properties as determined by the investigations of the pure scientists.

Many well known principles of science have lain unused for ages awaiting the practical application for which they were just suited. The power of steam was known long before the practical mind of Watt utilized it in the steam engine.

The engineer is probably an evolution of the artisan rather than of the early scientist. His work is becoming more scientific because of his relations and associations with the scientific world. These relations of the engineer to the sciences are of comparatively recent origin, and this fact accounts for the rapid development in the engineering and industrial world of the past half century. The results of this association have been advantageous to both the engineer and the pure scientist. The demands of the engineers for new discoveries have acted as an incentive for greater effort on the part of the investigators. In many instances the engineer is years in advance of the pure scientist in these demands; but, on the other hand, there are, no doubt, many valuable scientific facts now available which will yet work wonders when the engineer perceives their practical utility.

The engineer develops much more fully the faculty of discernment than does the abstract scientist, he is less visionary and more practical, less exacting and more commercial.

It is essential to progress that large stores of scientific knowledge in the abstract be accumulated and recorded in advance by the pure scientists, so that as the engineer encounters the necessity for their use he can employ them to the best advantage. The engineer must be familiar with these stores of useful knowledge in order to know what is available. This forms the scientific side of the engineer's work. While he must know what has been done by investigators, it is not absolutely necessary that he know how to make all such researches for himself; although, as before stated, there are times in an engineer's practice when such knowledge will not come amiss.

As engineers are specializing more and more, each particular specialty becomes more closely allied with the sciences that most affect it; consequently, to ensure the very best and most economic results in his work the engineer must keep in close touch with all of the scientific discoveries in his line.

The early engineers, owing to lack of scientific knowledge, took much greater chances in their constructions than is necessary for up-to-date modern engineers. There is now no occasion for an engineer to make any hazardous experiments in his structures, because by careful study of scientific records he can render his results certain.

In future the relations between engineers and the pure scientists will be even closer than they are to-day, for as the problems confronted by the engineer become more complex and comprehensive the necessity for accurate knowledge will increase.

The technical training now given engineers involves a great deal of the purely scientific; and it is evident that this training should be so complete as to give them a comprehensive knowledge of all the leading sciences that affiliate with engineering. There is no other profession that requires such a thorough knowledge of nature and her laws.

Of all the various divisions and sub-divisions of the sciences hereinbefore enumerated and of those tabulated in the Organizing Committee's "Programme," the following only are associated at all closely with civil engineering:—

Mathematics.
Geology.
Petrology.
Chemistry.
Physics.
Mineralogy.
Geography.
Astronomy.
Biology.
Botany.
Political Economy.
Jurisprudence.
Education.
Economics.

Attention is called to the fact that this list contains a number of divisions from the four main groups of pure sciences, viz., the mathematical, physical, physiological, and social, and but one division (economics) from the three groups of applied sciences, viz., the organic, constructive, and economic. The reasons why so little attention is to be given to the relation between civil engineering and the applied sciences are, first, in respect to organic science, there is scarcely any relation worth mentioning between this science and civil engineering, and, second, because the interrelations between civil engineering and other divisions of constructive science have already been treated in this address.

Of all the pure sciences there is none so intimately connected with civil engineering as mathematics. It is not, as most laymen suppose, the whole essence of engineering, but it is the engineer's principal tool. Because technical students are drilled so thoroughly in mathematics and because so much stress is laid upon the study of calculus, it is commonly thought that the higher mathematics are employed constantly in an engineer's practice; but, as a matter of fact, the only branches of mathematics that a constructing engineer employs regularly are arithmetic, geometry, algebra, and trigonometry. In some lines of work logarithms are used often, and occasionally in establishing a formula the calculus is employed; but the engineer in active practice soon pretty nearly forgets what analytical geometry and calculus mean. As for applied mechanics, which, as the term is generally understood, is a branch of mathematics (although it involves also physics and other sciences), the engineer once in a while has to take down his old text-books to look up some principle that he has encountered in his reading but has forgotten. Strictly speaking, though, engineers in their daily tasks utilize applied mechanics, almost without recognition; for stresses, moments, energy, moments of inertia, impact, momentum, radii of gyration, etc., are all conceptions of applied mechanics; and these are terms that the engineer employs constantly.

There are some branches of the higher mathematics of which as yet engineers have made no practical use, and prominent among these is quaternions. When it first appeared the conciseness of its reasoning and its numerous short-cuts to results gave promise of practical usefulness to engineers, but thus far the promise has not been fulfilled.

Notwithstanding the fact that the higher mathematics are of so little use to the practicing engineer, this is no reason why their study should be omitted from or even slighted in the technical schools; because when an engineer has need in his work for the higher mathematics he needs them badly; besides, the mental training that their study involves is almost a necessity for an engineer's professional success.

Geology (with its allied branch, or more strictly speaking subdivision, petrology) and civil engineering are closely allied. Civil engineers are by no means so well versed in this important science as they should be. This, perhaps, is due to the fact that the instruction given on geology in technical schools is mainly from books, hence most graduates find difficulty in naming properly the ordinary stones that they encounter, and are unable to prognosticate with reasonable assurance concerning what a proposed cutting contains.

Geology is important to the civil engineer in tunneling, railroading, foundations, mining, water-supply, and many other lines of work; consequently, he needs to receive at his technical school a thorough course in the subject given both by text-books and by field instruction.

A knowledge of petrology will enable the engineer to determine readily whether building stone contains iron which will injure its appearance on exposure, or feldspar which will disintegrate rapidly under the action of the weather or of acids from manufacturing establishments.

Next to mathematics, physics is undoubtedly the science most essential to civil engineering. The physicist discovers and formulates the laws of nature, the engineer employs them in "directing the sources of power in nature for the use and convenience of man." The forces of gravitation, adhesion, and cohesion; the pressure, compressibility, and expansibility of fluids and gases; the laws of motion, curvilinear, rectilinear, accelerated, and retarded; momentum; work; energy; the transformation of energy; thermodynamics; electricity; the laws of wave motion; the reflection, refraction, and transmission of light; and the mass of other data furnished by the physicist form a large portion of the first principles of civil engineering.

The function of applied mechanics is to establish the fundamental laws of physics in terms suitable for service, and to demonstrate their applicability to engineering construction.

Chemistry is a science that enters into closer relations with civil engineering than does any other science except mathematics and physics, and as the manufacture of the materials of engineering approaches perfection the importance of chemistry to engineers increases. Within a comparatively short period the chemist had made it possible by analyzing and selecting the constituents to control the quality of cast iron, cast steel, rolled steel, bronze, brass, nickel steel, and other alloys. The engineer requires certain physical characteristics in his materials, and obtains them by limiting the chemical constituents in accord with data previously furnished by the chemist. The proper manufacture of cement requires the combined skill and knowledge of the chemist and the mechanical engineer.

In water supply the chemist is called in to determine the character and amounts of the impurities in the water furnished or contemplated for use. The recent discovery that the introduction of about one part of sulphate of copper in a million parts of water will effectively dispose of the algæ, which have long given trouble, is a notable instance of the increasing interdependence of these two branches of science, as is also the fact that the addition to water of a small amount of alum will precipitate the earthy matter held in suspension without leaving in it any appreciable trace of the reagent.

In the purification of water and sewage, in the selection of materials which will resist the action of acids and the elements, and in the manufacture of alloys to meet various requirements, a thorough knowledge of chemistry is essential.

A knowledge of mineralogy is requisite for a clear understanding of the nature of many materials of construction, but is otherwise of only general interest to civil engineers.

Geography in its broad sense is related to civil engineering in some of its lines, for instance, geodesy and surveying, but generally speaking there is not much connection between these two branches of science.

Astronomy is perhaps more nearly related to civil engineering than is geography, although it is so related in exactly the same lines, for the railroad engineer on a long survey must occasionally check the correctness of his alignment by observations of Polaris, and the coast surveyor locates points by observations of the heavenly bodies.

Biology is allied to civil engineering mainly through bacteriology as applied to potable water, the treatment of sewage to prevent contamination of streams, and the sanitation of the camps of surveying and construction parties. The treatment of sewage has been given much more thorough study abroad than in this country, but the importance of its bearing upon life in the large cities of America is becoming better understood; consequently the progressive sanitary engineer should possess a thorough knowledge of bacteriology. In important cases, such as an epidemic of typhoid fever, the specialist in bacteriology would undoubtedly be called in; but a large portion of the work of preventing or eradicating bacterial diseases will fall to the lot of the sanitary engineer.

Botany comes in touch with civil engineering mainly, if not solely, in the study of the various woods used in construction, although it is a fact that a very intimate knowledge of this pure science might enable a railroad engineer or surveyor to determine approximately the characters of soils from the plants and trees growing upon them. A knowledge of botany is of no great value to the civil engineer, and much time is often wasted on its study in technical schools.

Political economy is a science that at first thought one would be likely to say is not at all allied to civil engineering; but if he did so, he would be mistaken, because political economy certainly includes the science of business and finance, and civil engineering is most assuredly a business as well as a profession; besides the leading engineers usually are either financiers themselves or advisers to financiers. Great enterprises are often evolved, studied, financed, and executed by engineers. How important it is then that they understand the principles of political economy, especially in its relation to engineering enterprises! It is only of late years that technical students have received much instruction in this branch of social science, and the ordinary technical school curriculum to-day certainly leaves much to be desired in respect to instruction in political economy.

Jurisprudence and civil engineering are closely allied in that engineers of all lines must understand the laws of business and the restrictions that are likely to be placed upon their constructions by municipal, county, state, and federal laws. While most engineering schools carry in their lists of studies the "Laws of Business," very few of them devote anything like sufficient attention to this important branch of science.

Are the sciences of civil engineering and education in any way allied? Aye, that they are! and far more than most people think, for there is no other profession that requires as much education as does civil engineering. Not only must the would-be engineer study the various pure and applied sciences and learn a great mass of technical facts; but he must also have in advance of all this instruction a broad, general education—the broader the better, provided that no time be wasted on useless studies, such as the dead languages.

The science of education is so important a subject for civil engineers that all members of the profession in North America, more especially those of high rank, ought to take the deepest interest in the development of engineering education, primarily by joining the special society organized for its promotion, and afterward by devoting some of their working time to aid this society in accomplishing its most praiseworthy objects.

The science of economics and that of civil engineering are, or ought to be, in the closest possible touch; for true economy in design and construction is one of the most important features of modern engineering. Every high-class engineer must be a true economist in all the professional work that he does, for unless one be such, it is impossible to-day for him to rise above mediocrity.

True economy in engineering consists in always designing and building structures, machines, and other constructions so that, while they will perform satisfactorily in every way all the functions for which they are required, the sum of their first cost and the equivalent capitalized cost for their maintenance, operation, and repairs shall be a minimum. The ordinary notion that the structure or machine which is least in first cost must be the most economical is a fallacy. In fact, in many cases, just the opposite is true, the structure or machine involving the largest first cost being often the cheapest.

Economics as a science should be taught thoroughly to the student in the technical school, then economy in all his early work should be drilled into him by his superiors during his novitiate in the profession, so that when he reaches the stage where he designs and builds independently, his constructions will invariably be models of true economy.

It has been stated that the relations between civil engineering and many of the pure sciences are very intimate, that the various branches of engineering, although becoming constantly more and more specialized, are so interdependent and so closely connected that they cannot be separated in important constructions, that the more data the pure scientists furnish the engineers the better it is for both parties, and that a broad, general knowledge of many of the sciences, both pure and applied, is essential to great success in the engineering profession.

Such being the case, the question arises as to what can be done to foster a still closer affiliation between engineering and the other sciences, and how engineers of all branches and the pure scientists can best be brought into more intimate relations, in order to advance the development of the pure sciences, and thus benefit the entire world by increasing the knowledge and efficiency of its engineers.

One of the most effective means is to encourage the creation of such congresses as the one that is now being held, and to so organize them and arrange their various meetings as to secure the greatest possible beneficial results.

Another is for such societies as the American Association for the Advancement of Science and the Society for the Promotion of Engineering Education to take into their membership engineers of good standing, and induce them to share the labors and responsibilities of the other members.

Conversely, the various technical societies should associate with them by admission to some dignified grade (other, perhaps, than that of full member) pure scientists of high rank and specialists in other branches of constructive science, and should do their best to interest such gentlemen in the societies' objects and development.

A self-evident and most effective method of accomplishing the desired result is to improve the courses of study in the technical schools in every possible way; for instance, by bringing prominent scientists and engineers to lecture to the students and to tell them just how scientific and professional work of importance is being done throughout the world, by stimulating their ambition to rise in their chosen profession, by teaching them to love their work instead of looking upon it as a necessary evil, and by offering prizes and distinctions for the evidence of superior and effective mental effort on the part of both students and practicing engineers.

There has lately been advanced an idea which, if followed out, would aid the development of engineering more effectually than any other possible method, and incidentally it would bring into close contact scientists in all branches related directly or indirectly to engineering. It is the establishment of a great post-graduate school of engineering in which should be taught in every branch of the profession the most advanced subjects of all existing knowledge that is of real, practical value, the instructors being chosen mainly from the leading engineers in each specialty, regardless of the cost of their services. Such specialists would, of course, be expected to give to this teaching only a few weeks per annum, and a corps of regular professors and instructors, who would devote their entire time and energies to the interests of the school would be required. These professors and instructors should be the best that the country possesses, and the inducements of salary and facilities for investigation that are provided should be such that no technical instructor could afford to refuse an offer of a professorship in this school.

Every modern apparatus needed for either instruction or original investigation should be furnished; and arrangements should be made for providing means to carry out all important technical investigations.

It should be the duty of the regular faculty to make a special study of engineering literature for the benefit of the profession; to prepare annual indices thereof; to put into book form the gist of all technical writings in the transactions of the various engineering societies and in the technical press that are worthy of being preserved and recorded in this way, so that students and engineers shall be able to search in books for all the data they need instead of in the back files of periodicals; to translate or assist in the translation of all engineering books in foreign languages, which, in the opinion of competent experts, would prove useful to engineers or to the students of the school; and to edit and publish a periodical for the recording of the results of all investigations of value made under the auspices of the institution.

In respect to what might be accomplished by such a post-graduate school of engineering the following quotation is made from the pamphlet containing the address in which the project was advanced:—*

"The advantages to be gained by attendance at such a post-graduate school as the one advocated are almost beyond expression. A degree from such a school would always ensure rapid success for its recipient. Possibly for two or three years after taking it a young engineer would have less earning capacity than his classmates of equal ability from the lower technical school, who had gone directly into actual practice. However, in five years he certainly would have surpassed them, and in less

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*Higher Education for Civil Engineers. An Address to the Engineering Society of the University of Nebraska, April 8, 1904, by J. A. L. WADDELL, D. Sc., LL. D.

than ten years he would be a recognized authority, while the majority of the others would be forming the rank and file of the profession, with none of them approaching at all closely in reputation the more highly educated engineer.

"But if the advantages of the proposed school to the individual are so great, how much greater would be its advantages to the engineering profession and to the entire nation! After a few years of its existence there would be scattered throughout the country a number of engineers more highly trained in the arts and sciences than any technical men who have ever lived; and it certainly would not take long to make apparent the impress of their individuality and knowledge upon the development of civil engineering in all its branches, with a resulting betterment to all kinds of constructions and the evolution of many new and important types.

"When one considers that the true progress of the entire civilized world is due almost entirely to the work of its civil engineers, the importance of providing the engineering profession with the highest possible education in both theoretical and practical lines cannot be exaggerated.

"What greater or more worthy use for his accumulated wealth could an American multi-millionaire conceive than the endowment and establishment of a post-graduate school of civil engineering."

Another extremely practical and effective means for affiliating civil engineering and the other sciences is for engineers and professors of both pure science and technics to establish the custom of associating themselves for the purpose of solving problems that occur in the engineers' practice. Funds should be made available by millionaires and the richer institutions of learning for the prosecution of such investigations.

Another possible (but in the past not always a successful) method, is the appointment by technical societies of special committees to investigate important questions. The main trouble experienced by such committees has been the lack of funds for carrying out the necessary investigations. and the fact that in nearly every case the members of the committees were unpaid except by the possible honor and glory resulting from a satisfactory conclusion of their work.

Finally, an ideal but still practicable means is the evolution of a high standard of professional ethics, applicable to all branches of engineering, and governing the relations of engineers to each other, to their fellow workers in the allied sciences, and to mankind in general.

As an example of what may be accomplished by an alliance of engineering and the pure sciences, the construction of the proposed Panama Canal might be mentioned. Some years ago the French attempted to build this waterway and failed, largely on account of the deadly fevers which attacked the workmen. It is said that at times the annual death rate on the work ran as high as six hundred per thousand. Since the efforts of the French on the project practically ceased, the science of medicine and biology have discovered how to combat with good chances for success the fatal malarial and yellow fevers, as was instanced by the success of the Americans in dealing with these scourges in the City of Havana after the conclusion of the Spanish-American war.

The success of the American engineers in consummating the great enterprise of excavating a navigable channel between the Atlantic and Pacific Oceans (and concerning their ultimate success there is almost no reasonable doubt) will depend largely upon the assistance they receive from medical science and its allied sciences, such as hygiene, bacteriology, and chemistry.

Geological science will also play an important part in the design and building of many portions of this great work, for a comprehensive and correct knowledge of the geology of the Isthmus will prevent the making of many costly mistakes, similar to those that resulted from the last attempt to connect the two oceans.

Again, the handling of this vast enterprise will involve from start to finish and to an eminent degree the science of economics. That this science will be utilized to the utmost throughout the entire work is assured by the character and professional reputation of both the Chief Engineer and the members of the Commission.

Notwithstanding, though, the great precautions and high hopes for a speedy and fortunate conclusion of the enterprise with which all concerned are starting out, many unanticipated difficulties are very certain to be encountered, and many valuable lives are likely to be expended on the Isthmus before the first steamer passes through the completed canal. Engineering work in tropical countries always costs much more and takes much longer to accomplish than is at first anticipated; and disease, in spite of all precautions, is very certain to demand and receive its toll from those who rashly and fearlessly face it on construction works in the *tierra caliente*. But with American engineers in charge, and with the finances of the American Government behind the project, success is practically assured in advance.

What the future of civil engineering is to be, who can say? If it continues to advance as of late by almost geometrical progression, the mind of man can hardly conceive what it will become in fifty years more! Every valuable scientific discovery is certainly going to be grasped quickly by the engineers and put to practical use by them for the benefit of mankind, and it is only by their close association with the pure scientists that the greatest possible development of the world can be attained.

INDEX.